ANALYSIS OF THE ROLE OF ETBE IN SUPPLYING REFORMULATED GASOLINE TO REGIONAL MARKETS

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EXECUTIVE SUMMARY

The U.S. petroleum refining industry currently is undergoing some of the most extensive restructuring in its more than hundred year history, as it struggles to comply with the fuel reformulation mandates of the 1990 Clean Air Act Amendments (CAAA). These required changes in refinery operations and gasoline blending present major challenges, as well as potential market expansion opportunities for the U.S. ethanol industry and for small U.S. refiners. For this study, the required gasoline formulations in 1995 and 1998 have been integrated with existing and potential production capacity of gasoline blending stock through the use of an expanded and regionalized REFORMGAS model. The REFORMGAS model runs yield a number of trends that will be important for the Biofuels Program and for the future utilization and pricing of alcohol fuels and alcohol-based ethers.

General Trends in the Gasoline Market 1995 - 2000

1. **Gasoline blending will become increasingly seasonal and regionalized in the period 1995 - 2000**, with summertime gasoline in areas of severe ozone problems varying significantly from wintertime gasoline in terms of volatility, aromatics content, and oxygenate blending. Whereas formerly gasoline blends were altered seasonally primarily for reasons of vehicle driveability and regionally for climatic conditions, in the future gasolines will be produced according to formulas designed to lower carbon monoxide formation and to reduce levels of ozone, oxides of nitrogen (NO_x), and volatile organic compounds (VOCs).

2. **Gasoline blending will increasingly be dominated by mandated federal and state reformulation concerns**, making the refining and blending process much more complex than it has been to date. Limits on aromatic levels, olefins content, and volatility (measured as Reid Vapor Pressure or RVP) will be paramount concerns for refiners, with olefins and aromatics levels being the limiting constraint in many locations in the country.

3. **Gasoline refiners have a limited number of short-term reformulation options but a large number of long-term refinery operation options to meet new gasoline standards.** They can **add desirable blendstock** (TAME, TAEE, ETBE, MTBE, alkylate), increasing the size of the pool and diluting existing undesirable components. They can, in the refining process, **remove** undesirable components (i.e., benzene), although this reduces the overall pool volume and creates the problem of finding a market for the extracted material. Third, they can **transform** parts of the refinery slate into new products or blending stock, primarily through the installation of new equipment (i.e., alkylation or isomerization units). The third approach provides an almost endless set of output options for the refinery operator, but often requires very large capital investments and considerable lead time.

4. **In the period 1995 - 2000, the average level of octane in gasoline will rise**, due in large measure to rising use of oxygenates in gasoline as part of CAAA emissions reduction strategies. The overall U.S. gasoline pool will contain 1.5 - 2.0% oxygen, even in the summertime, with the upper limits on oxygenate use being mainly concerns about NO_x increases. RVP and levels of aromatics will be the major concerns for gasoline blenders, particularly in the nine worst ozone areas where reformulated gasoline is required. The need to reduce aromatics by 25 - 30% by the year 2000 in certain non-attainment areas will often be the binding constraint for the gasoline refiner.

General Trends in the Use of Ethanol in the Gasoline Market after 1995

1. Starting in 1995, ethanol will have two distinct roles in the U.S. gasoline market:

- splash-blended oxygenate/octane source, and
- feedstock for the creation of butyl and amyl ethers.

Which of these roles ethanol plays will vary by season and will be highly region-specific largely dictated by the need to meet increasingly demanding 1990 CAAA gasoline formulation requirements.

2. **Concerns about gasoline volatility will severely limit the use of splash-blended ethanol as a gasoline additive in the summertime**, (even with the continuation of the current ethanol federal tax exemption), unless the current 1.0 pound/square inch (psi) gasohol waiver is continued -- or replaced by some compromise like the Bush Ethanol/Espy Initiative currently being considered in Congress. At the same time, low RVP ceilings will increase the desirability to gasoline blenders of ETBE and TAEE. Without the current 1.0 psi waiver that 10% ethanol/90% gasoline blends receive, the use of ethanol for summertime splash blending will virtually cease except in areas with large state subsidies in addition to the existing federal tax exemption.

3. As CAAA mandates become increasingly strict in the period 1995 - 2000, the use of ethyl and methyl ethers as blending stock will rise very rapidly, limited mainly by the availability of C4 intermediate products -- isobutylenes and isoamylenes from fluidized catalytic cracking (FCC) units -- that are required for the etherification process.

4. **The use of ethanol-based ethers will increase most rapidly in areas with the most severe summertime ozone pollution problems.** In these cases, phase 2 (complex option) gasoline will most likely be required by the year 2000, and few blending materials[1] will provide the low RVP, high octane, and freedom from aromatics that

[1]Use of the most common oxygenate -- Methyl Tertiary Butyl Ether or MTBE -- will be severely limited in many areas because of its blending RVP of 8.0 psi.

complex option gasoline will require. The demand will be marginally greater when the ethanol tax exemption is extended to ETBE and TAEE as well.

5. **Overall demand for ethanol is expected to grow rapidly in the period 1995 - 2000, mostly to serve as refinery processing feedstock** (See Table ES-1). By 1998, REFORMGAS estimates that U.S. summertime ethanol demand could reach 97,500 - 148,500 barrels/day or B/D (4.1 - 6.0 million gallons/day) for ether feedstock and another 5,000 - 8,000 B/D for ethanol splash-blending, while wintertime demand for ethanol as a splash-blended additive and as a feedstock for ether production could grow to the range of 103,000 - 133,000 B/D (4.3 - 5.6 million gallons/day). By 1998, this would require annual U.S. ethanol production of 31 - 45 million barrels/year (1.3 - 1.9 billion gallons/year), or 50-100% above current annual production. At the same time, ETBE capacity could grow to equal that of MTBE, or 25,000-50,000 B/D by 1998.[2]

6. These forecasts are based on ethanol availability at current prices including the ($39-40/B) federal tax exemption. Sharply lower prices (i.e., $25-32/B) for ethanol, such as those envisioned by the NREL Biofuels program for the late 1990s, would sharply increase the demand for ethanol for splash-blending and for ether production. The demand for ethanol-based ethers alone could push ethanol demand to 125,000 B/D or more.

7. **While ethanol-based ethers (ETBE and TAEE) have a number of highly desirable gasoline blending characteristics that should cause demand to rise rapidly, they still must compete with less expensive methanol-based ethers (MTBE and TAME) for a role in the U.S. gasoline blending pool.** Therefore, use of ethanol-based ethers can expand rapidly only to the extent that their blending characteristics outweigh their higher cost and that FCC feedstock is available for etherification (and not being used for the production of less expensive blendstocks).

The Impacts of Wide Spread Opt-ins

1. **If numerous states chose to "opt-in" in 1995 to the federal phase one (simple) reformulated gasoline standards, the overall effect could be a major increase in the use of all oxygenates in gasoline, with the butyl and amyl ethers being in greatest demand.**

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[2]This does not necessarily mean new "greenfield" ETBE plants. It is highly likely that much of the current and planned MTBE capacity will be reconfigured, at relatively low cost, to enable refiners to switch between MTBE and ETBE production according to seasonal blending needs.

Table ES-1: Estimated Ethanol and Ethanol-based Ether Demand[3] by PADD for 1998 Complex Option Case			
Ethanol Demand (000 B/D)	**Winter**	**Summer**	**Average**
Padd 1			
Ethanol	9-10	0-2	3-5
Ethers	4-6	15-35	10-15
Padd 2			
Ethanol	15-20	0-1	5-7
Ethers	10-15	15-28	12-20
Padd 3			
Ethanol	15-25	5	10-15
Ethers	5-10	25-38	15-20
Padd 4			
Ethanol	5	0	2-3
Ethers	10	7.5	6-8
Padd 5			
Ethanol	10	0	2-4
Ethers	20-25	35-40	20-30
Totals			
Ethanol	**54-70**	**5-8**	**22-34**
Ethers	**49-66**	**97.5-148.5**	**63-93**

[3] These annual averages are based on slack demands in the spring and fall seasons, when concerns about emissions and RVP are reduced. The ranges for winter and summer demands reflect both the uncertainty over such facets of the CAAA as opt-ins and spillover as well as the effects of the tax treatment of ethanol as a blend and in ethers.

2. If more than a few small states chose to adopt the stricter-than-federal California gasoline standards, the U.S. refining system will be unable, in the near-term, to supply all the needed California standard gasoline with the U.S. refining system projected to exist for the 1995 - 1997 time period. In the short-term, imports of finished gasoline would probably rise sharply. In order to meet these specifications, refiners may be forced not to make incremental changes to existing refineries but to drastically restructure refining operations to create very low volatility/low aromatic base gasoline. Once this new refining capacity is in place in the period 1998 - 2000, new opportunities for the use of ethanol as an octane enhancer/oxygenate may arise.

3. The existence of a substantial domestic ETBE and/or TAEE production capacity by 1998 would reduce or eliminate much of the need to import finished gasolines and would reduce U.S. import dependence.

Federal Tax Incentives and the Use of Ethanol and Ethanol-Based Ethers in Gasoline

1. Biomass-based ethanol which is blended into gasoline currently receives an effective federal tax exemption of $0.54/gallon. There is consideration of extending this favorable tax exemption to ethers derived from ethanol. REFORMGAS sensitivity analyses show that there will be substantial demand for ETBE even if the ethanol subsidy is eliminated across the board. The ethanol federal subsidy of $0.54/gallon or $22.68/barrel, after allowing for inefficiencies in the catalytic etherification process, would amount to approximately $8.19/barrel for ETBE.

2. Even when this proposed subsidy is not applied, the REFORMGAS model projects that there could be substantial summertime demand for ETBE by 1998 in both PADDs II and III. This is particularly true whenever low RVP levels have to be achieved and where the source of cheap octane (heavy aromatics) are severely constrained. In the 1998 summertime complex model case, where the level of aromatics has to be sharply reduced from 1990 standards, REFORMGAS predicts that even without the ethanol subsidy the demand for ETBE could reach as much as 27,000 B/D in PADD II and another 40,000 B/D of ETBE and 33,000 B/D of TAEE in PADD III. Wide-spread opt-ins would further increase these figures.

RVP Waiver for Ethanol

The RVP waiver is central to the continued use of ethanol as a splash-blending agent, but not to the continued use of ethanol in gasoline. Eliminating the RVP waiver (but maintaining the ethanol subsidy) would have the effect of sharply increased use of other oxygenates, including ETBE.

Amyl vs. Methyl Ethers

Amyl ethers (TAME and TAEE) have characteristics that make them somewhat more attractive than butyl ethers (ETBE and MTBE) as gasoline blending compounds. They have very low blending RVPs (close to 0 in the case of TAEE), high octane, and high boiling points (which make them very useful for the dilution of high boiling point compounds such as benzene. Amyl ethers are not yet produced in major commercial quantities, but the technology for doing so is commercially available. If the prices for the two sets of ethers are approximately equal, then demand could shift in favor of the amyl ethers, particularly in circumstances where the CAAA restrictions are particularly severe toward volatile organic compounds (VOCs), aromatics, and RVP.

However, while it is relatively easy and inexpensive to build capacity that can readily switch between MTBE and ETBE, the same is <u>not</u> true for switching between butyl (MTBE, ETBE) and amyl (TAME, TAEE) ethers. Amyl ether capacity will have to be built new, at considerable expense.

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1.0 Introduction

The passage of the 1990 Clean Air Act Amendments (CAAA) marked a major change in the regulatory approach of the United States federal government in lowering air emissions from mobile sources. Whereas previous federal air quality legislation had focused on lowering the release of pollutants through the setting of tailpipe emissions standards (this requiring major changes in vehicle emissions control technologies), the CAAA focused on regulating the **composition** of fuels sold in the areas not in compliance with National Ambient Air Quality Standards. The most vexing problem was that of ground-level ozone, which occurs in dangerous levels when sunshine serves as a powerful catalyst in the presence of certain ozone precursors, chiefly volatile organic compounds (VOCs) and oxides of nitrogen (NO_x). For the most serious ozone non-attainment areas, the CAAA mandated that states within which these non-attainment areas are located must adopt "reformulated" gasoline during peak summertime ozone periods and provided specific guidance on what the composition of reformulated gasoline should be. This is to be done in two phases, which go into effect in 1996 and 2000 respectively. States that have moderate ozone non-attainment areas are also permitted, under the CAAA, to petition the Environmental Protection Agency (EPA) to "opt-in" to the reformulated gasoline standards. California was considered a special case, since it had already enacted an aggressive program requiring reformulated fuels and low or zero emissions vehicles, and so is allowed to have fuel standards (henceforth California specifications or California standards) that are more restrictive than the federal standards. The major differences between 1990 industry standard gasoline, phase I and phase II reformulated gasoline, and California reformulated gasoline are shown in Table 1-1 below.

To meet these specifications, U.S. petroleum refiners and blenders are engaged in an unprecedented level of capital investment, refinery modification, and experimentation with new blending components. Of particular concern to gasoline producers and blenders is the need to simultaneously add oxygen, reduce volatility (as measured by the fuel's Reid Vapor Pressure or RVP), and remove benzene and aromatics, while maintaining octane ratings and vehicle driveability. Initially there were major questions raised as to whether it would be possible to supply the blending ingredients required prior to 1995, with particular attention paid to the availability of oxygenates[4], but these have receded in the face of the successful initiative of the 1992 wintertime oxygenated fuels program in carbon monoxide non-attainment areas.

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[4] Refer to the National Petroleum Council, Petroleum Refining in the 1990s: Meeting the Challenges of the Clean Air Act, June 1991. This influential study relied on extensive interviews with petroleum corporation managers to reach composite predictions that oxygenate supplies would be tight but adequate in 1995, and would then loosen as new productive capacity was added in the mid and late 1990s.

In mid-1990, prior to the passage of the CAAA, the Biofuels Systems Division of the U.S. Department of Energy commissioned Meridian Corporation to begin examining the impacts of proposed gasoline reformulation on the market for oxygenates and on the U.S. petroleum

Table 1-1: CAAA Mandated Gasoline Oxygenation and Reformulation

	Oxygenated Gasoline	Phase I Gasoline Reformulation	Phase II Gasoline Reformulation
Pollutant Controlled	Carbon Dioxide (CO)	Ozone	Ozone
Applies to What Areas?	Serious or moderate non-attainment areas	Severe or extreme non-attainment areas	Severe or extreme non-attainment areas
Start-up Date	Oct-Dec 1, 1992	Jan 1, 1995	Jan 1, 2000
Mandated Gasoline Oxygen Content	2.7% or greater	at least 2.0% by weight year-round	at least 2.0% by weight year-round
Volatility (RVP) Upper Limit during control period	N/A	8.1 psi maximum	8.1 psi maximum
Allowable Benzene Content	N/A	No more than 1% 0.95% average	No more than 1% 0.95% average
Allowable Heavy Metals Content	N/A	0% (Jan 1, 1996)	0%
% of Aromatic Hydrocarbons Content	N/A	26.2% maximum and 25% pool average	Will be published by EPA December, 1993
Decrease in Aromatic HCs & Olefins Emissions from 1990 Industry Average	N/A	15%	25%

N/A = Not Applicable

refining sector. The result was the development of the Refinery Environmental Formulation Optimization Requirements Model or REFORM, a linear optimization model that developed least cost solutions for the 1995 U.S. national gasoline pool that met the CAAA gasoline formulation requirements. While very useful for examining the national requirements for oxygenates, looking at the impacts for various proposed gasoline formulations, and for predicting the resulting wholesale gasoline price increases, the REFORM model was designed specifically to be a national model.

However, after the implementation and rule-making for the CAAA had begun, it became apparent that many of the most interesting analytical questions, and most of the serious potential oxygenate shortages, would occur at the state or regional level. Refineries, pipelines, and blending stock production facilities are not distributed evenly across the United States, creating infrastructure issues. Fuel demand and vehicle miles traveled is also growing at different rates in different states and regions. State governments were required by the CAAA to develop state implementation plans for the achievement of clean air standards, and their responses were often dominant considerations in the need for reformulated gasoline. The clearest example is California, with its large gasoline demand, high levels of ozone pollution, plans for stricter-than-federal fuel formulation, and lack of infrastructure connection with other U.S. petroleum districts. PADD V (the West Coast), also appeared to have more serious oxygenate supply issues, particularly if urban areas outside California opted in to reformulated gasoline standards. Therefore, the REFORM model was transformed into a partially regionalized model called REFORMGAS[5], which included detailed modules for PADD V (the West Coast) and PADD I (the East Coast). It was the results of this analysis[6] that pointed out the potentially important role to be played by ETBE and other ethers[7] with low blending vapor pressures.

Ethers are a particularly attractive form of gasoline blending component because

- they can be created in refineries using existing feedstocks,
- are oxygenated,
- have relatively low blending vapor pressures and high octanes, and

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[5] REFORMGAS stands for REfinery Formulation Optimization Required for Manufacturing GASoline. There are winter and summer versions of the model for the years 1995 and 2000, and modules for each of the key Petroleum Administration for Defense District or PADD.

[6] See Donald I. Hertzmark and John H. Ashworth, "Difficulty in Meeting Clean Air Act Amendments," Fuel Reformulation, March/April 1992, pp. 25 - 30.

[7] ETBE is Ethyl Tertiary Butyl Ether, and it is created by the catalytic combination of ethanol and isobutane. Other key ethers are MTBE (Methyl Tertiary Butyl Ether), TAME (Tertiary Amyl Methyl Ether), and TAEE (Tertiary Amyl Ethyl Ether). For an examination of the performance and chemical characteristics of ETBE vs MTBE and other oxygenates, see Tshiteya, Vermiglio and Tice, Properties of Alcohol Transportation Fuels: Alcohol Fuels Reference Work #1 (Alexandria, VA.: Meridian Corporation for the DOE Biofuels Systems Division, May 1991), Section 9.

- produce a finished gasoline which can be shipped and stored in existing pipelines and tankfarms.

In addition, because of the volumes required to reach 2.0 or 2.7% oxygen, certain ethers would, by dilution, significantly reduce the levels of other controlled substances in gasoline such as toxics and sulfur.

Based on results reported in 1992 of the partially regionalized REFORMGAS analysis, NREL tasked Meridian Corporation to develop the analytic capability to "examine the national market for ETBE and other oxygenates and to determine regional production of oxygenates to meet these requirements." Based on discussions with NREL and DOE staff, it was determined that in revising the REFORM model, particular attention should be paid to five oxygenates: ethanol, the two key butyl ethers (MTBE and ETBE) and the two amyl ethers (TAME and TAEE). NREL instructed Meridian to complete the regionalization of the REFORMGAS model, by developing "regional modules for PADDs 2 and 3, which currently serve as suppliers of finished gasoline and other petroleum products for PADDs 1 and 5. The subcontractor shall create finished modules for PADDs 2 and 3, and would link them to the existing modules for PADDs 1 and 5. Further detail would be added into the models so that they can now differentiate between foreign sources (i.e., Venezuela) and movements from other PADDs." The model development activities are reported in Section 2. The results of model runs and subsequent analysis are reported in Sections 4 and 5 below. Appendices A-D contain summary sheets of various REFORMGAS runs and sensitivity analyses.

In addition to this analytic task, NREL also asked that Meridian Corporation briefly examine "possible configurations, using ETBE and other oxygenates, that will allow small refiners to continue operating as producers of final products." With the passage of the Clean Air Act Amendments, there had been expressed concern that the large capital investments required to upgrade existing refineries might be beyond the means of older small U.S. refiners, and they might be forced to either become only wholesale suppliers of blending materials to larger refiners or go out of business. Because of the low vapor pressure and the oxygen content of ethers such as ETBE, they have been seen as major potential options for smaller refineries striving to meet fuel reformulation mandates. Section 6 examines options for small refiners and the role of ETBE and other ethers.

Lastly, Section 7 provides a number of suggestions for future analysis and model development. As state responses to the CAAA become more clear, and as more states indicate their interest in opting in to the federal reformulated gasoline standards, the regional and national impacts can be determined with greater clarity. In addition, this regional analysis can also be helpful in determining geographic areas where future demand would be sufficient to support major production facilities for ethanol, ETBE, and/or TAEE, and would assist NREL/DOE in their search for industrial partners for scale-up facilities for ethanol production.

2.0 Model Development Activities for this Report

2.1 *Creation of PADD II and PADD III modules*

The primary modeling activity covered by this report was to develop REFORMGAS modules for PADDs II and III. Extending the REFORMGAS modeling to the two central petroleum districts presented special problems and concerns. PADD II, covering the Midwest and Mississippi Valley, is a major refiner and producer of oil and oil products. At the same time, that PADD imports a significant volume of gasoline from PADD III, the Gulf Coast region. In addition, about half the crude oil in PADD II comes from PADD III. PADD II is also a significant trader of crude oil with Canada. PADD III is the major refining center in the country and exports most of the gasoline used in PADD I, the East Coast. As a result, it is crucial to keep careful track of where the gasoline from PADD III is destined.

2.2 *The Development of the Complex Options*

Gasoline to be sold in non-attainments areas in the period 1995 - 1996 are being evaluated under the EPA "simple" model, which is currently available. After this period, a complex model still under development will be used. For gasoline sold in ozone non-attainment areas that are still not in compliance by 1998 with National Ambient Air Quality Standards, there will be additional requirements to introduce a (phase 2) reformulated gasoline that will further reduce the level of volatile organic compounds (VOCs) in gasoline. The specifications for Phase i and Phase 2 reformulated gasoline are provided in Table 1-1. This additional requirement, coupled with other mandated gasoline requirements, have been incorporated within REFORMGAS into a 1998 "complex" scenario, which is provided for the work undertaken for PADDs II and III in this report.

2.3 *Options for Refinery Improvements*

In the current work, one of the key issues has been the location of expected refinery improvements. Given the need to increase the supply of oxygenated, low VOC gasoline in PADD II, will the investments in refining capacity take place in that PADD's refineries or in PADD III, the main refining center of the country? A number of alternatives were examined, consistent with both the announced refinery upgrading projects and the commercial and logistical realities of the gasoline markets.

These alternatives include the following:

- ✓ Additional ether capacity;
- ✓ Use of FCC unit catalysts that provide olefin-rich streams for ether and alkylation units;

- ✓ Increased alkylation capacity; and
- ✓ Pretreatment of reformer feedstocks to reduce benzene precursors and aromatics.

2.4 *Addition of Amyl Ethers*

Based on earlier REFORM and REFORMGAS model results with PADDs III, V and I, it was decided to include the amyl ethers, TAME and TAEE, in the current REFORMGAS modeling effort. These ethers use different olefin streams from the butyl ethers, MTBE and ETBE, and appear to be compatible with new catalysts that allow FCC units to coexist more readily and profitably with etherification and alkylation units. Adding the amyl ethers also extends the usefulness of methanol since TAME has a lower blending vapor pressure than does MTBE. In addition, the section of the model that computes shadow prices was enhanced so that shadow prices for both capacity additions (more ether production, for example) and for the product itself would be computed.

As in earlier versions of the REFORM and REFORMGAS models, each of the five U.S. PADDs is subdivided into airsheds so that the severity of gasoline standards can be modified readily and realistically. The gasoline demand levels are consistent with DOE predictions of gasoline demand in the year of analysis (1995 or 1998).

The models for PADDs II and III are connected through both the imports of refined products into PADD II from PADD III and the imports of crude oil. Thus it is the distillation model, not the gasoline blending model, that provides consistency of the data among the various PADDs.

In the future it may be useful to subdivide the models of PADDs II and III in a manner consistent with DOE/Energy Information Administration's own PADD subdivisions. For PADD II, this subdivision would enable the analyst to segregate the regions that are dependent on trade with Canada from those that depend on PADD III. Similarly, it will be useful for separating the markets for gasohol blends in Winter from areas that will be using ethers for oxygen.

3.0 Key Overall Trends in Gasoline Refining, 1994 - 2000

Gasoline blending will become increasingly seasonal and regionalized in the period 1995 - 2000, with summertime gasoline in areas of severe ozone problems varying significantly from wintertime gasoline in terms of volatility, aromatics content, and oxygenate blending. Whereas formerly gasoline blends were altered seasonally primarily for reasons of vehicle driveability and regionally for climatic conditions, now gasolines will be produced according to formulas designed to lower carbon monoxide formation, reduce levels of ozone, oxides of nitrogen (NO_x), and volatile organic compounds (VOCs).

Gasoline blending will increasingly be dominated by mandated federal and state reformulation concerns, making the refining and blending process much more complex than it has been to date. Limits on aromatic levels and volatility will be paramount concerns for refiners, with aromatics levels being the limiting constraint in many locations in the country. Under the Simple Option (Phase 1 reformulated gasoline) of the CAAA, affected areas must use oxygenated fuel in the Winter and relatively non-volatile fuel in the Summer. The Complex Option (Phase 2 reformulated gasoline) mandates more stringent reductions in Summer gasoline volatility. For both PADDs, different implementations of the Complex Option were assessed in the analysis for this report. These options included varying degrees of opting-in and different availabilities of compliant blendstocks.

Winter gasoline generally requires far less reformulation than does the Summer gasoline. Essentially, the addition of ethanol or an ether up to the volume required for meeting the oxygen target will require only that some reformate and FCC naphtha be removed from the fuel stream.[8] Key considerations of aromatics levels, RVP, and increased Summer gasoline demand are factors which make the focus on Summer blends appropriate.

Several features about the post-CAAA gasoline market are already clear, and they are largely independent of whether or not emerging oxygenates (such as ETBE and the amyl ethers TAME and TAEE) are produced in large quantities:

- More octane will be available, on average, as 85 - 90 octane materials are replaced by or converted in part to blend stock of more than 100 octane.

[8] For example, butane, long a low cost octane enhancer, easily blended and stable during shipment, is essentially unusable in summer blends due to its high blending RVP. However, butane will still be used in the Winter blends.

- The gasoline pool will contain about 1.5 - 2% oxygen, even in summer months since ethers are the only blending components with low volatility that allow refiners to simultaneously reach a number of key objectives.[9]

- Pre-treatment of reformer feeds (naphthas) to remove benzene precursors will be required to keep these materials in the gasoline pool at levels approximating their traditional historic values.

- Of the key gasoline characteristics – RVP and levels of aromatics and olefins content – it will be the aromatics and olefins levels that will be more crucial in determining which additives will be required to meet future blending requirements.

- Research octane (RON) will be a binding determinant of gasoline quality, as it was in the REFORMGAS simulation runs used for this analysis.

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[9] Heavy reformates contain high aromatic levels, which means that they must be used sparingly despite their higher octane and low RVPs.

4.0 Summer Gasoline Findings

4.1 *National and Regional Base Case Blending Results*

By the mid-1990s the U.S. gasoline pool will have made several important compositional changes. These changes reflect 1990 CAAA decisions about gasoline and air quality. The most important of these changes are the following:

- High levels of oxygenates;
- High levels of alkylates - up to 15-20% of the Summer pool;
- Reduced use of reformates and FCC naphthas due to benzene and VOC problems; and
- Reduced use of normal Butane due to RVP problems.

The tables in this section outline the 1996-97 gasoline pool without consideration of the Complex Option implementation of the Clean Air Act Amendments. This Base Case represents just the aggregate national gasoline blends that will be required including attainment and non-attainment areas.

<u>Base Case for Late 1990s</u>

The reformulation requirements of the 1990 Clean Air Act will lead to some significant changes in the composition of the gasoline pool. In particular, the following changes are either under way or will be implemented shortly:

- Reformate will be subjected to benzene removal. Reforming severity will decline in summer to reduce aromatics content. Octane will fall as a result of reduced severity. The proportion of reformate in the pool, as well as absolute levels of reformate used, will fall from current levels;[10]

- Catalytic cracked naphthas will fall slightly as a proportion of the remaining gasoline pool while the composition of the cracked naphthas will change by season and also by regulatory regime;

- If olefins are more strictly controlled than is currently expected, then light Fluidized Catalytic Cracked Naphthas (FCCNs), which are comprised of more than 40% olefins, will be used as feedstocks for other processes, including alkylation and etherification;

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[10] Reduced reforming severity will reduce C_4 output along with octane. With C_4 demand in such other refinery operations as alkylation going up, this decline in reforming represents a potential refinery bottleneck.

- If aromatics continue to be seen as the prime hazard in fuels, then heavy cracked naphthas, with 60% aromatics will be "deselected" catalytically;

- Other naphthas should rise to 5-7% of the pool but will not increase much in absolute terms;

- Alkylates will be in great demand, particularly in summer when their combination of good octane and low levels of aromatics, olefins, and benzene makes the material relatively more valuable;

- Oxygenates and ethers should rise to about 10% of the gasoline pool as demand rises not only for oxygen but also for the low benzene, aromatics, and olefins levels that characterize oxygenates and ethers. Ethanol blending for gasohol will be restricted during the summer by the effects of ethanol on vapor pressure, even with the one pound RVP waiver for ethanol blends;

- Butanes will continue to be attractive during the winter but their high blending RVPs will drive summer use close to zero; and

- Imports of gasoline are expected to rise sharply, to around 7-10% of the pool, as some refiners choose to shut down rather than spend the funds necessary to comply with the Clean Air Act.[11]

To get a better idea of just how the CAAA will change the gasoline pool in the late 1990s, Meridian analysts have constructed a Least-Cost Base Case for the winter and summer gasoline pools for that period. These cases were designed to examine what components the gasoline market would demand based solely on cost and physical characteristics. Therefore, they exclude the current ethanol tax exemption and RVP waiver. They include some but not all of the changes required by the 1990 CAAA. The major difference between the Base Case and the Simple Option (which includes all the changes required for 1995 Phase 1 reformulated gasoline) is that the RVP and the level of aromatics are higher than allowed under the CAAA. However, the base case does include the approximate levels of fuel constituents that gasoline refiners recommended in 1990 as being appropriate for major emissions reductions at the lowest possible cost. These cases are national and do not show the particular gasolines that will be used in such airsheds as the

[11] For some smaller refiners, their current refinery configuration might not have sufficient upgrading capability to permit the addition of alkylation units. As a result, these refiners might be forced to sell their gasoline output to larger refiners as an intermediate blending component.

South Coast Basin of California in high summer.[12] Another caveat regarding the REFORMGAS results is that the model shows what is required to achieve a solution - i.e., the type of gasoline that will satisfy both quality and environmental constraints - at the requisite volumes. However, it is not certain that sufficient conversion capacity, especially for alkylates and ethers, can be constructed, particularly in PADD V, where summer standards for vapor pressure and volatility may be the most stringent. Table 4-1 below shows the major components of the pool in the late 1990s for both the summer and winter base cases.

Table 4-1: Composition of 1996-1997 Gasoline Pool, Least-Cost Base Option; Entire U.S. Market (Without Ethanol Tax Exemption and RVP Waiver)

Component	Proportion of the Gasoline Pool (%)	
	Winter	Summer
Reformate	38	23
Catalytic Naphtha (FCCN)	14	24
Other Naphthas	15	11
Alkylate	9	17
Oxygenates	10	11
Butane	3.5	2
Imports	10	10

Note: Figures may not add to 100 due to rounding.

During the winter, refiners must shift the operation of catalytic cracking units to meet the demand for distillate fuel oil. Thus the FCCN component of the pool will fall during the winter, especially in light of the large volumetric contribution required from ethers and oxygenates.[13]

[12] The *REFORM* model does base the average figures used on the general types of gasolines that are required in each region of the country. For the gasolines particular to an airshed, less highly aggregated versions of *REFORM* must be used.

[13] Demand for reformate rises due in part to the need for additional hydrogen inside the refinery to desulphurize middle distillates and fuel oils.

The base case crude oil price for this analysis is in the middle range of current predictions for that commodity in the late 1990s at $23.55/barrel for West Texas Intermediate (WTI), the NYMEX marker crude.[14]

4.2 *1995 Simple Option Results*

National Gasoline Pool Composition

The CAAA "Simple" (Phase One reformulated gasoline) option achieves a gasoline pool similar to the Base Case. As shown in Table 4-2, the only real difference between the two is the control over summer levels of VOCs in the Simple Option. The Winter blend under the Simple Option is the same as that in the Base Case, and so is not shown in Table 4-2. In the Simple Option, no ethanol is used in the summer gasoline without tax and RVP incentives. The second column shows the effects of the incentives on the demand for various blending components under the Simple Option if there is no oxygen content ceiling.

Table 4-2: Composition of 1996-1997 Gasoline Pool, Simple Option, No Oxygen Content Ceiling; Entire U.S. Market

Component	Proportion of Gasoline Pool (%)	
	Summer Without Tax and RVP Waivers	Summer with Tax and RVP Waivers
Reformate	23	15
Catalytic Naphtha (FCCN)	24	28
Other Naphthas	11	19
Alkylate	17	11
Oxygenates	11	22
Butane	2	3
Imports	10	3

Note: Figures may not add to 100 due to rounding.

[14] With WTI at $23.55/bbl, Arab light would be landed at the U.S Gulf Coast at about $22-23/bbl while Alaska North Slope crude would be landed at the Gulf for just over $19/bbl.

As Table 4-2 shows, if the current 3.7% oxygen content ceiling is not imposed on the gasoline pool to prevent increased NO_x output, the federal tax exemption and the 1.0 psi waiver would change the composition of the gasoline pool more dramatically than that realized in 1995 under the base case prior to the 1995 implementation of the CAAA. In particular, the market for reformate is virtually eliminated except for the "Lite" version.[15] The high octane level of ethanol in blends generally reduces greatly the demand for other octane boosters including butane and alkylate. Without an oxygen content ceiling, ethanol would be blended at above 10% levels in most attainment areas, replacing imported gasolines. However, the resulting gasoline pool would be over 5% oxygen (wt.), which would clearly violate the 1990 CAAA injunction that NO_x levels are not allowed to increase. No consideration is given to driveability problems that may arise from the high level of O_2.

PADD III: Summer Simple Option[16]

In PADD III the Simple Option requires a significant reformulation of the gasoline supply. In particular, refiners will need to make virtually all of their oxygenate investments just to meet the 1995-1996 gasoline pool standards. Reduced RVP, together with low levels of VOCs, limits refiners' abilities to use many of the reformed and cracked naphtha fractions. The combination of climate and limited blending options combines to produce a gasoline pool that varies little from the ethanol subsidy case to the free-market case. Table 4-3 below shows the cases with and without subsidies/waivers for gasoline composition in PADD III. The subsidy causes refiners to blend slightly more oxygenates and the fuel cost is about $0.30/B less than without the subsidy.

4.3 *1998 Complex Option Results*

National Gasoline Pool under the Complex Option

The Complex Option will require that the entire gasoline pool go through some degree of reformulation. Two of the key ingredients, reformate and cracked naphthas, will emerge with fewer VOCs and octane than previously. With investments in reducing the emissivity of standard components of the pool, fewer alkylates and oxygenates will be required for the entire Summer season.

[15] "Lite" reformate is low severity reformate. By pre-treating reformer feed, the output will have reduced levels of aromatics, benzene and octane.

[16] In the REFORMGAS PADD III module, the system is forced to accept nominal volumes of Butane and toluene/xylene in the Summer. The 200 b/d hardly affects the overall emissivity of the fuels and the exercise was done to obtain shadow prices for valuing reductions in the use of such components.

Table 4-3: Composition of 1996-1997 Gasoline Pool; PADD III		
Component	Proportion of Gasoline Pool (%)	
	Summer without Tax and RVP Waivers	Summer with Tax and RVP Waivers
Reformate	28	29
Catalytic Naphtha (FCCN)	21	21
Other Naphthas	12	12
Alkylate	19	19
Oxygenates	9	10
Butane	0.07	0.07
Imports	11	9

Note: Figures may not add to 100 due to rounding.

The Complex Option requires less addition of higher octane material to achieve market specifications. The main effect of the subsidies to ethanol under the Complex Option is to shift additional demand to ethyl ethers (ETBE and TAEE) (see Table 4-4). The use of the low RVP and low VOC ethyl ethers allows the use of more reformed and cracked naphthas, while maintaining pool quality. The reader should note that the demand for gasoline exports from PADD III to both PADDs I and II are additional to this output.

4.4 *Demand for ETBE and TAEE under Differing Scenarios*

National Level

At the national level, the demand for the ethyl ethers is largely for ETBE in the period prior to 2000. Several of the simulations using the amyl ether, TAEE, were undertaken as a means of assessing the potential marketability of that product. The national level simulations determined the maximum demand for ethyl ethers by limiting the volume of MTBE that is available to that which will be produced in the U.S. by 1998. The MTBE produced abroad is expected to be used to meet environmental mandates in other countries. As much as 450,000 B/D of ethyl ethers, about 6% of the gasoline pool, could be used to meet the Summer gasoline pool reformulation, were supply to be sufficient. Demand at that level is induced by the tax exemption and the RVP waiver for ethanol and ethanol blends. About 200,000 B/D of ethanol would be required to meet such a demand for ethyl ethers.

Table 4-4: Composition of 1997-1998 Gasoline Pool, Complex Option; Entire U.S. Market		
Component	Proportion of Gasoline Pool (%)	
	Summer Without Tax Exemption and RVP Waivers	Summer with Tax Exemption and RVP Waivers
Reformate	25	31
Catalytic Naphtha (FCCN)	27	26
Other Naphthas	9	9
Alkylate	13	13
Oxygenates	7	9
Butane	3	3
Imports	15	8

Note: Figures may not add to 100 due to rounding.

Note: In undertaking the runs described below, it was important to develop both shadow prices (the value to the gasoline pool for an additional barrel of an ingredient) and demand levels. Shadow prices only occur when demand exceeds supply – i.e., when the product is at its upper or lower bound. Therefore, the capacity to provide a commodity, such as ethanol, ETBE, or TAEE, has been set just slightly below what the gasoline demands -- thereby producing a shadow price.

Without sufficient ethanol supplies, or without the subsidies, other means would be required to meet the demand for low emissivity fuels. MTBE would be the big gainer. U.S. demand for that ether would rise by almost 300,000 B/D in the least cost scenario. Barring imports or domestic production of MTBE at levels of 450-475,000 B/D, imports of finished gasoline must rise to about 14-15% of the overall Summer pool to meet emissions specifications.[17]

[17] Alkylate could satisfy much, but not all, of this demand given sufficient investment in alkylation units and in feedstock production. However, alkylates do not have a low enough blending RVP to eliminate the need for ethers.

PADD III Demand

Simple Option:

In the Simple Option case, about 43,000 B/D of ethyl ethers will be required in 1995-96. Almost two thirds of this total is ETBE. Demand for the ethyl ethers will rise slightly with the federal tax exemption for ethanol. However, the Simple Option does not require the level of reformulation which would result in the demand for ethyl ethers above 3-4% of the pool.

Complex Option:

With the need to further reformulate the PADD III pool, the demand for ethers increases to 74,000 B/D, about 6% of the pool. More than half of the total ethers are ethanol-based, requiring greater than 30,000 B/D of ethanol to meet this demand. This demand is at the upper limit of ether capacity so that the tax exemption does not affect demand.

Complex Option/California Standards:

Sensitivity analyses were undertaken to examine the impacts of the adoption of the stricter-than-federal California gasoline specifications, and the results of those REFORMGAS runs are reported in Appendix C. About 80,000 B/D of ethyl ethers are needed to meet the requirements of the high opt-in summer pool. At this level the relative tax treatment of ethanol is of little importance. The demand for the ethyl ethers is due largely to the need to meet very low RVP levels, unattainable using methyl ethers.

Exports from PADD III to PADDs I and II:

Two types of gasoline are exported to PADD II. The first is a slightly reformulated blend with compliant levels of RVP, benzene, etc. The second is intended to be used to bring other gasoline streams into compliance and beats the relevant specifications on the main criteria of RVP, octane and VOCs. This latter blend is about 400-425,000 B/D and contains about 20-30% alkylate.

The ethers contained in the 700,000 B/D of standard gasoline exported to PADD II will be mostly MTBE, unless higher levels of ethanol production combine with favorable tax treatment to increase the use of ethyl ethers. Climate also plays a role since the peak pollution season in PADD II is shorter in the northern part of the district than it is along the East Coast and in PADD V. However, strong incentives to blend ethyl ethers could make some difference in the gasoline blend that goes to PADD II. Of the 1.2 million B/D of exports to PADD II, about 400,000 B/D is likely to contain ethyl, rather than methyl ethers. This could mean as much as 25,000 B/D of ethyl ethers for the high compliance gasoline. Such a blend would require as much as 9-10,000 B/D of ethanol.

Some ethyl ethers will be needed for the PADD III exports to PADD I. That region contains several cities with significant ozone problems in the summer that will call for very low RVP fuels. However, with sufficient time and investment, refiners can furnish an alkylate-rich fuel (20-30%), in their exports to PADD I, that will use little oxygenate. For the summer period simulations, we have found that a gasoline that is similar to the PADD V high summer blend along with another, more volatile gasoline for current attainment areas, will allow refiners to meet the standards.

PADD II

Simple Option:

In the Simple Option case, about 22,000 B/D of ethyl ethers will be required in 1995-96. All of this total is ETBE. Demand for the ethyl ethers is not affected by the tax exemption for ethanol. However, the Simple Option does not require the level of reformulation that gets the demand for ethyl ethers above 3-4% of the pool. Moreover, PADD II receives 1.1-1.2 million B/D of oxygenated gasoline from PADD III. Of these imports, about 40% is the highly reformulated blend that is needed in the non-attainment areas such as Chicago and St. Louis. The remainder of the imports will go to areas that are currently in compliance with the CAAA mandates for ozone. The reformulation of these latter gasolines is designed to keep these areas in compliance, not to reduce emissions from their current levels.

Complex Option:

With the need for further reformulation of the PADD II pool, the demand for ethyl ethers stays at 27,500 B/D, about 1% of the pool. An additional 50,000 B/D of methyl ethers is used, largely due to the lower price of the natural gas-based methanol feedstock, even with ethanol receiving the federal income tax exemption. More than 12,000 B/D of ethanol will be needed to meet this demand. This demand is at the upper limit of ether capacity so that the ethanol tax exemption does not affect demand. The imported gasolines will contain an additional 50,000 B/D of alcohols (110-125,000 B/D of ethers). As long as opt-ins are limited, a relatively small volume of ethers will meet the fuel specifications.

Complex Option/California Standards:

As was the case with PADD III, sensitivity analyses were undertaken to examine the impacts of the adoption of the stricter-than-federal California gasoline specifications on PADD II, and the results of those REFORMGAS runs are included in Appendix C. A program of local or regional opt-ins that reduced the aromatics and olefins levels by about 10 percent (2 percentage points and 1 percentage point, respectively) would be manageable within the current refining system in PADD II, provided that imported gasolines bore the brunt of the cleanup. As a result, the local ether figures remain unchanged from the earlier totals. In this case, the relative tax treatment of ethanol is of little importance. The demand for the ethyl ethers is due largely to the need to meet very low RVP levels, unattainable using methyl ethers.

A requirement to move to California-type standards for most urban areas within PADD II would require vastly more reformulation. Ether requirements within PADD II would rise to more than 115,000 B/D, about 45% from ethyl ethers. Demand for ethanol for ether use would rise to over 20,000 B/D within the PADD along with 10,000-15,000 B/D more for ethyl ethers in imported gasolines. The current federal tax exemption and RVP waiver policies would increase the demand for ethanol but at the expense of ethyl ethers. The demand for such ethers would fall by 14,000 B/D (27%) or 5,000 B/D of ethanol. However, the demand for ethanol for blends would rise by almost 28,000 B/D, providing a net change of 23,000 B/D over the no subsidy case. Total demand for ethanol would rise to over 43,000 B/D for the period in which the regulations were in force.

Implications for Ethanol Research

The overwhelming conclusion from this work is that the demand for ethyl ethers will grow as the CAAA is implemented. The more stringent the implementation, the greater the demand for ethyl, rather than methyl ethers. Their unique combinations of low volatility, high octane and low RVP make them ideal for blending into pipeline shipments of gasoline.

Ethanol as a component of gasohol will be virtually unusable in non-attainment areas during summer periods without the current 1.0 psi RVP waiver. Attention needs to focus on use of ethanol in ethers. It is clear that given adequate supplies, the very low blending RVPs of ethyl ethers provide refiners with the ability to effect less stringent reformulation of the remainder of the gasoline pool. In the simulation results for PADD II, refiners were able to use more "lite" reformate and relatively less alkylate, the more ethyl ethers they had to blend.

As far as plant location is concerned, the implication from this work is that more ethanol will be used in PADD III than elsewhere. The ethanol contained in exports of gasolines to other PADDs along with use within the PADD could take all of the current output of ethanol in the U.S. If ethyl ethers are not to be supply constrained, then refiners will need to build more facilities near oil refining centers.

4.5 *Shadow Prices for Ethanol, ETBE, and TAEE under different Scenarios*

One of the key analytical outputs of an optimization project is the set of shadow prices that accompany the main solutions. These shadow prices show the value to the problem of a relaxation of a constraint or of a variable bound. In the current case, the shadow prices give the value of changing levels of blending components or of altering environmental constraints. For example, the shadow price of aromatics (in $/BBL) gives the value of relaxing the aromatics constraint by one barrel. If this figure is $75/bbl, then it means that a one barrel addition to the aromatics pool (i.e., a relaxation of the upper limit on aromatics) will save that amount. Since aromatics now sell for about the same price as gasoline and since that shadow price is more than twice the average *ex refinery* gasoline cost, this result says that under certain circumstances refiners will be willing to pay a great deal to reduce the aromatics levels in their gasoline pool. On the other hand, blending components that do not add aromatics to the pool will be worth correspondingly more.

At the national level, the calculation of shadow prices can obscure the important regional effects of different refinery capabilities and configurations. This report focuses attention on the PADD level shadow prices, especially for the more stringent cases. The shadow prices calculated by the REFORMGAS model give important clues to the feasibility of the analytical results. In particular, the reader should take care to note the following interpretations of the model's shadow prices:

- High negative shadow prices for ethanol in the summer time reflect the value to the model of a reduction in the induced or mandated use of at least some ethanol as gasohol, not ether;

- Higher values for ethers reflect the multitude of gasoline formulation environmental constraints satisfied by those compounds -- oxygen content, lack of aromatics or olefins, low RVP -- as well as their high octane rating;

- Where summer RVP level is a problem, the amyl ethers (TAME and TAEE) and ETBE will be more highly valued than MTBE; and

- The shadow prices for the CAAA-imposed environmental constraints -- aromatics content, olefins content, RVP, and oxygen content -- all represent the cost reduction from relaxing the constraint by one unit (1 bbl). For the emissions level constraints (aromatics, olefins, and RVP), such relaxation is equivalent to the cost reduction for a refiner of allowing one more barrel of olefins or aromatics into the pool. For the oxygen constraint, relaxation is equivalent to the cost saving from allowing one less barrel into the pool.

The results of the REFORMGAS PADD II and PADD III runs with the existing ethanol tax exemption are given in Tables 4-5 and 4-6 below. Figures 4-1 and 4-2 provide graphic representations of various shadow prices for PADD II. Figures 4-3 and 4-4 provide graphic representations of the PADD III data. As shown in Figures 4-2 and 4-4, the tax exemption has a major impact on shadow prices in the complex option, where the blending process is highly constrained.

Interpreting the shadow prices always requires some judgement and can lead to confusion. This is particularly true for national averages, where the calculation of shadow prices can obscure the important regional effects of different refinery capabilities and configurations.

However, even at the PADD level there are a number of typical inferences that can be made for the shadow prices in REFORMGAS:

Table 4-5: Shadow Prices of Gasoline, Ethers, and Oxygenates; PADD II (With Ethanol Tax Exemption)

Component	Shadow Price ($/bbl)				
	Summer Base Case	Summer Simple Option	Summer Complex Option	Summer CA Standards	Winter Opt-in; Complex Option
Gasoline	$35.54	$40.44	$41.34	$0.00	$33.00
Olefins	$0.00	$7.60	$0.42	$7.90	$0.00
Aromatics	$5.33	$9.20	$0.00	$39.37	$1.54
Ethanol	$0.00	($1.18)	$0.00	$0.00	$32.44
ETBE	$0.00	$6.83	$2.12	$4.61	$13.72
TAEE	$0.00	$0.66	$0.00	$0.00	$6.68
TAME	$0.26	$7.45	$4.21	$4.98	$14.57
MTBE	$1.81	$9.36	$4.55	$6.82	$19.97

Figure 4-1
PADD II Shadow Prices (w/Ethanol Tax Exemption)

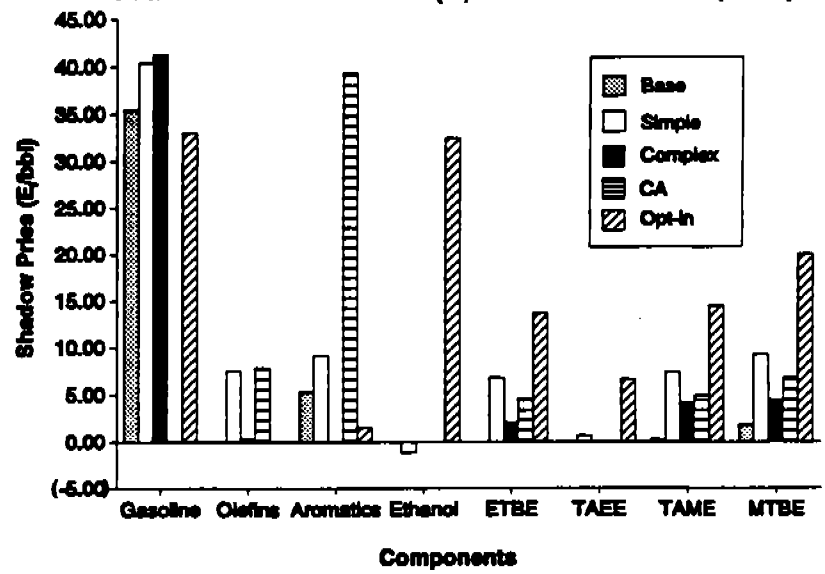


Figure 4-2
PADD II Shadow Prices for Complex Option
(w/ and w/o Ethanol Tax Exemption)

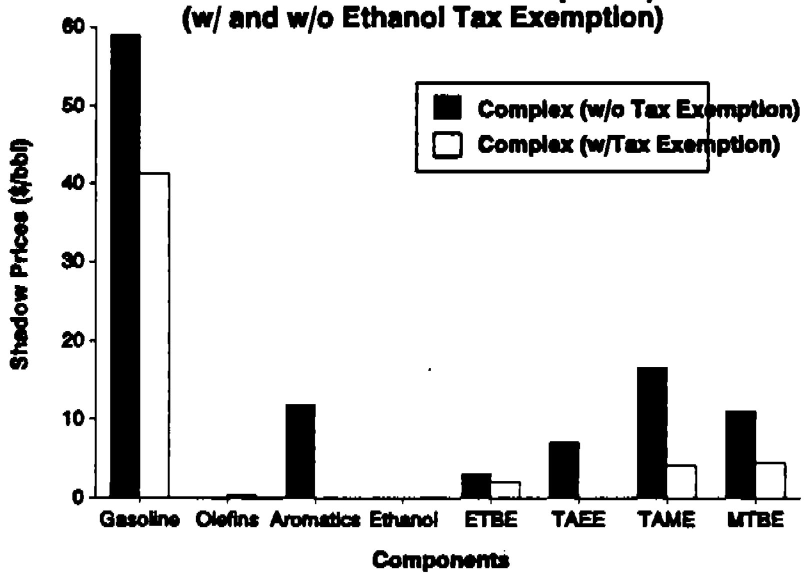


Table 4 - 6: Shadow Prices of Gasoline, Ethers, and Oxygenates; PADD III (With Ethanol Tax Exemption)					
	Shadow Price ($/bbl)				
Component	Summer Base Case	Summer Simple Option	Summer Complex Option	Summer CA Standards	Winter Opt-in; Complex Option
Gasoline		$45.01	$81.27	$267.83	N/A
Olefins		$0.00	$0.00	$27.78	N/A
Aromatics		$12.87	$50.04	$301.31	N/A
Ethanol		$0.00	($36.60)	($30.99)	N/A
ETBE		$0.32	$24.22	$145.26	N/A
TAEE		$0.61	$34.45	$203.96	N/A
TAME		$4.20	$34.73	$188.08	N/A
MTBE		$2.95	$14.27	$73.90	N/A

N/A Winter (Complex Option) Opt-in Scenario not relative to PADD III region since no CO non-attainment areas exist in the region.

Figure 4-3
PADD III Shadow Prices (w/Ethanol Tax Exemption)

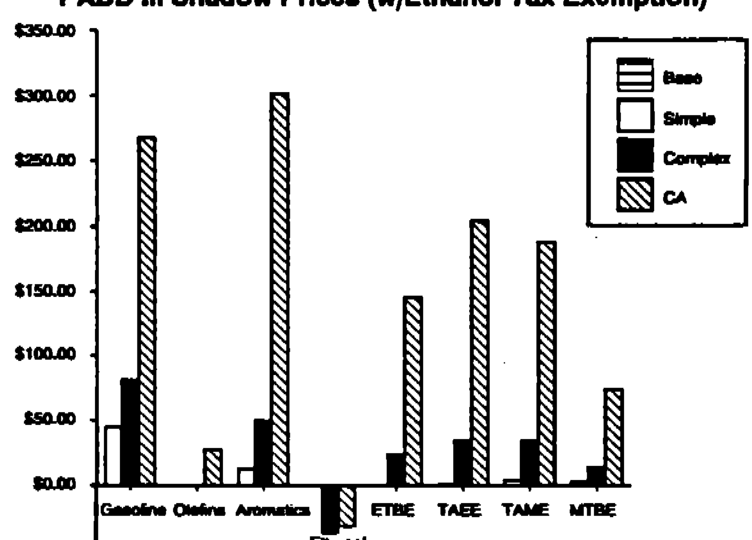
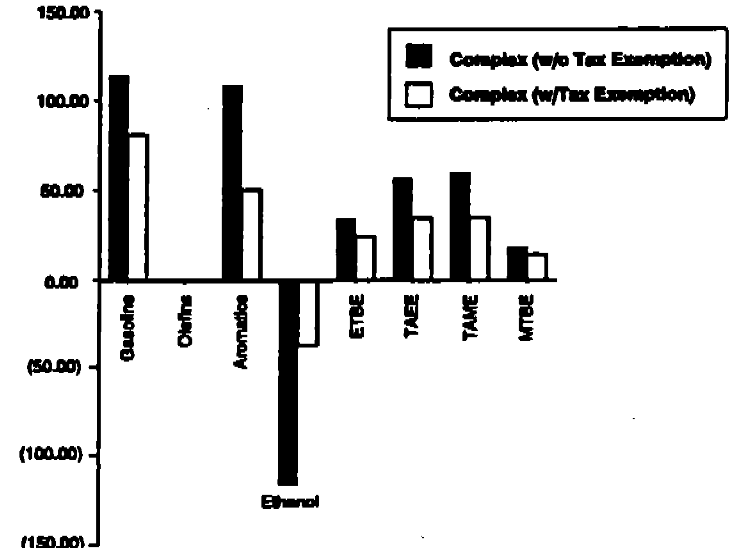


Figure 4-4
PADD III Shadow Prices for the Complex Option
(w/ and w/o Ethanol Tax Exemption)



- The cost of relaxing one of the pollution constraints (aromatics content, olefins content, etc.) represents the net cost of such replacement. Since the aromatics come with such desirable traits as high energy octane and low RVP numbers, the shadow price is the net cost of such replacement and not necessarily the market value of one barrel of benzene or toluene;

- The shadow price of additional gasoline supplies represents the cost of making up gasoline from the limited pool of low emissivity, high octane ingredients - hence the high costs in Summer situations;

- The high summertime shadow prices for ethanol reduction represent the high cost of adding ethyl ethers to the gasoline supply to counterbalance the high blending RVP of the ethanol. This high shadow price does not obtain in winter months where only the oxygen value of the ethanol is important.

- For smaller refiners, the shadow prices of the ethers and oxygenates will be far higher than for the refiners with highly efficient conversion facilities since the latter group has more options for reducing emissions and adding back octane.

Implications for Ethanol Program

As was previously indicated, the highest value use for ethanol is in ethers. Where feedstocks are available, the amyl ethers appear to be superior to the butyl ethers. However, where RVP is the critical constraint, the ethyl ethers are desirable relative to the methyl ones.

5.0 Winter Gasoline Findings

In contrast to the vast complexity of supplying summer gasolines with the appropriate characteristics, the winter gasoline pool merely requires two questions to be answered:

- How much oxygen is required? and
- How much spillover will there be?

The 1990 CAAA required the use of oxygenated gasoline starting in the late fall of 1992 for serious or moderate carbon monoxide (CO) non-attainment areas. The gasoline sold in these areas during the CO control period must contain 2.7% or greater oxygen by weight. Volatility is not an issue, so the formulation process is much less complex than in the summertime.

5.1 *National Base Case Blending Results*

The major reformulation of the winter gasoline pool will be completed by the end of 1997. Key components of the winter blend are shown in Table 5-1. Much of the FCC stock will be given over to ether and alkylate feedstock production. Reformates will be primarily the "lite" variety, with the reduced octane made up by the oxygenates.

Table 5-1: Composition of U.S. National 1996-1997 Winter Gasoline Pool

Component	Proportion of Gasoline Pool (%)
	Winter
Reformate	38
Catalytic Naphtha (FCCN)	14
Other Naphthas	15
Alkylate	9
Oxygenates	10
Butane	3.5
Imports	10

Refiners will choose to keep the reforming units operating at a high level in order to obtain the hydrogen that they require for treating high sulphur fuels. The lower severity of the "lite" reforming will itself reduce hydrogen supplies.

5.2 *PADD II Base Case Blending Results*

Since the winter gasoline formulation, due to environmental mandates, is of interest only for PADD II (PADD III has no serious or moderate CO non-attainment areas which would require oxygenated winter gasoline), only PADD II results will be reported here. However, PADD III does supply much of the winter oxygenated gasoline used in PADDs I and II. As a result, the output of winter reformulation is accounted for in the individual PADD I and II reports.

The key changes in gasoline content between summer and winter are the use of butane in the blends and the increased use of full reformate. In a situation of limited spillover, with oxygen demand limited to the major cities and urban areas of PADD II, the effect of the oxygen mandates will be minimal. Indeed, one of the most interesting features of PADD II 1995 wintertime gasoline is that **it contains less oxygen than summer blends will.** The summer gasolines use oxygenates as essential blending materials to meet the complex CAAA requirements covering RVP, volatile organics, octane, and benzene. Without the oxygenates, it is not clear how summer gasoline blends could come into compliance, especially if current moderate non-attainment areas opt-in to the higher standards. The increased cost of meeting the winter standards for PADD II (over the base case) is about 1-2¢/gallon ($0.50-1.00/bbl) *ex refinery*.

Butane displaces naphthas directly while most of the oxygen is supplied through imports of oxygenated gasolines from PADD III. Table 5-2 below shows the typical PADD II gasoline blend for the winter 1995 period.

The differences between the simple and complex case for PADD II are relatively small. More oxygenates will be blended into the gasoline pool, and less finished would be imported from PADD III. Table 5-3 shows the projected wintertime gasoline pool for 1997 and beyond.

Widespread spillover of oxygenated gasolines or significant opt-ins by marginal non-attainment areas will change the economics and blending requirements. The use of oxygenated gasolines by gasoline vendors in all of the metropolitan areas of PADD II will raise the average cost of gasoline by a further 3¢/gallon over the standard winter blend. Imports from PADD III, reformates and FCC naphthas are all reduced to make way for additional volumes of the more costly oxygenated additives. Without other impediments to its use, such as pipeline compatibility, ethanol blends will be a key means of meeting the higher oxygen standards. If it is not necessary to go the ether route, either for RVP or for quality and standardization, then ethanol is the easiest way to introduce more oxygen to the pool. However, it should be noted that movement of oxygenated gasolines from one state to another would be inhibited by the quality problems that accompany use of gasohol in the winter.

Table 5-2: Composition of 1996-1997 Gasoline Pool, Simple Option; PADD II		
Component	Proportion of the Gasoline Pool (%)	
	Winter Without Tax Exemption	Winter With Tax Exemption
Reformate	17	14
Catalytic Naphtha (FCCN)	17	18
Other Naphthas	4	4
Alkylate	8.5	9.5
Oxygenates	2	3
Butane	3	3
Imports	48	48

Table 5-3: Composition of 1996-1997 Gasoline Pool, Complex Option; PADD II		
Component	Proportion of the Gasoline Pool (%)	
	Winter Without Tax Exemption	Winter With Tax Exemption
Reformate	16	15.5
Catalytic Naphtha (FCCN)	19	16
Other Naphthas	7	7
Alkylate	8	7
Oxygenates	5	5
Butane	3	3
Imports	42	47

5.3 *Implications for Ethanol Production and Research*

Wintertime use of ethanol as a splash-blending agent is a cost-effective way of providing the needed oxygen content and octane. Because there is little concern for fuel volatility during the winter, 10% ethanol/90% gasoline blends will probably remain a major option for providing required oxygenate in PADD II CO non-attainment areas. There will be two key issues: transporting the oxygenated fuel to market, and the level of additional opt-ins. Much of the gasoline for PADD II is provided by refineries in PADD III, and that fuel normally moves to market via pipeline. The refiner has the option of adding the oxygenate at the refinery (in the form of MTBE, TAME, ETBE, or TAEE) or shipping a sub-octane base gasoline which is then splash-blended with ethanol by the wholesaler (since virtually all pipeline companies refused to handle fuels containing ethanol because of phase-separation issues). If the ethanol is to be used for splash-blending, the production facility should be located in PADD II. If it is to be used for production of butyl or amyl ethers (ETBE or TAEE), the ethanol production facility should be co-located with a major petroleum refining complex in PADD III, where it could supply major gasoline markets in PADD II and I. The level of wintertime demand for PADD II will be largely influenced by the level of opt-ins to the oxygenated gasoline standard. Large-scale opt-ins will provide a major boost to ethanol usage, since ethanol is a cost-effective option for the provision of oxygen in this region.

The implications of the wintertime gasoline findings for the Biofuels Program are less clear-cut than those for the summertime. There is no major market incentive to focusing on producing inexpensive ethanol-based ethers for wintertime use, because ethanol is readily acceptable as a splash-blending agent. However, the fact that PADD II is dependent on distant refineries for its fuel supplies does point toward producing ethanol-based oxygenates that can be used in common carrier pipelines, such as ETBE and TAEE.

6.0 The Role of Ethanol-Based Ethers in Helping Small Refiners Survive

Small U.S. petroleum refiners confront a series of relatively unpleasant choices in their effort to remain competitive and yet produce gasoline that meets the CAAA specifications. Many of the refineries operated by these firms are small, and currently have only a small degree of flexibility in the stream of refinery products that they can produce due to their limited installed capacities in sophisticated refining processes (etherification, isomerization, etc.).

Ethanol as a blendstock will be of particular importance to small refiners operating in markets that contain no serious or severe ozone non-attainment areas. So long as the 1.0 psi ethanol waiver stays in place, ethanol will provide cost-effective octane so that levels of toxics (benzene, toluene, etc.) and aromatics can be reduced at a relatively low cost. Ethanol would also displace imported gasoline, particularly in areas like PADD II and PADD I.

For small refiners, major gasoline reformulation will be far more difficult. Faced with the need to produce Phase 1 reformulated gasoline by 1995 and Phase 2 reformulated gasoline by the year 2000, they will need to take one of the following routes:

- make large capital investments to drastically alter their capability to modify the existing finished product slate;
- add new units (i.e., etherification or alkylation capacity) that enable them to produce additional blending components that will bring their existing gasoline into compliance;
- set up long-term arrangements to purchase needed blending components from specialized suppliers; or
- shift into being a wholesale supplier to larger refiners of intermediate products which are then upgraded to finished gasoline or diesel fuel.

For refiners, the least expensive option for initial Phase 1 gasoline reformulation is to produce a cleaner stream of output from existing units through the use of feedstock pretreatments and new catalysts. In some cases, advanced small refiners will be able to increase reforming capacity with low aromatic feedstocks and increase their alkylation output sufficiently to meet specification. The most severe problem for small refiners will be the production of highly reformulated summertime gasoline. If they can't afford major overhauls of existing processing facilities, then some refineries will have to reduce operations or close due to their inability to provide a gasoline with the required specifications.

Small refiners often have limited access to low-cost capital relative to larger integrated petroleum firms that are oil producers/refiners/marketers, which make massive upgrade projects beyond their borrowing (and repayment) means. They also experience greater difficulty getting major upgrade modifications to their facilities done rapidly, because the large petroleum industry architectural and engineering (A&E) firms are already fully engaged in upgrade work for the large integrated refiners. On the other extreme, the small refiners do not want to become only wholesale intermediate product suppliers, because this is much less profitable and more subject to cancellation than the production of finished gasoline. **This means that the addition of new units, such as etherification or alkylation trains, may be the cost-effective solutions for these firms to stay in the gasoline business. ETBE and TAEE units may be particularly attractive because these are superior as blending stock to their methanol-based analogues, having lower RVPs, higher octane, and more dilution of CAAA-restricted components (benzene, butane, etc).** Recent studies have indicated that ETBE can be produced via the steam cracking or fluidized cracking of butylenes for $0.84 - $0.89/gallon in 1995 and $0.77 - 0.81/gallon by the year 2000.[18] While this is considerably above the cost of MTBE production, due primarily to very low prices for the methanol feedstock, the ETBE offers a considerable potential to the small refiner, particularly when it is under pressure to sharply lower the volatility of summertime gasoline. The capital investment for steam cracker or fluidized cracker units is relatively modest, compared with other potential options (alkylation units, for example).

If a small refiner already has an MTBE unit, then the capital cost of converting it to produce ETBE (or to create a joint ETBE/MTBE capability) is slight -- only about $200,000.[19] With the refiner being able to take advantage of the federal tax exemption for the ethanol feedstock, this conversion might provide the flexibility that will enable a small PADD II or PADD III refiner to stay in business.

[18] See R.M.Tshiteya and D.H.Hertzmark, Economic Evaluation of Biomass-Based Fuels and Chemicals for Transportation (Alexandria, VA.: Meridian Corporation for the National Renewable Energy Laboratory, September 1993), pgs 6-22 and 6-23. These figures assume that the ethanol tax exemption of $0.54/gallon is passed proportionately to the 42% ethanol content for ETBE, resulting in a subsidy of $0.22/gallon.

[19] Ibid, p. 6-21.

7.0 Recommendations for Future Analysis and Model Development

When initially conceived in 1990, the REFORM model was seen primarily as a means for determining approximate future national demand for ethanol due to the mandates of the 1990 Clean Air Act Amendments. At that time, ethanol was seen primarily as a splash blended oxygen source/octane enhancer for gasoline or as a future neat fuel in dedicated fuel vehicles. There was little information about the performance and blending characteristics of ethanol-based ethers or on other low RVP blending stock that could be used to alter the physical characteristics of the final blended gasoline. At that time, there was no way to predict the detailed state and federal regulations that would be developed to implement the 1990 CAAA, or of the steps that would be taken by fuel producers and retailers to provide low emissions transportation fuels.

While the REFORM and REFORMGAS models have been evolving in direction and complexity, so have the regulatory and implementation environment within which clean alternative fuels will operate in the period 1995 - 2000. In mid and late 1993, four major issues have arisen which will require detailed analysis and, in one or two cases, additional fine-tuning of the REFORMGAS model. Each of these will be briefly addressed separately below.

7.1 *Regional Fuel/Vehicle Standards and the Impacts of Opt-ins*

Under the 1990 CAAA, states always have the right to opt for stricter-than-federal air quality standards and vehicle specifications. In 1993, individual states or groups of states on a regional basis have moved to enact stricter-than-federal mandates, usually built around the California specifications. The major example is the Ozone Transport Region, made up of ten states in the Northeast, which is considering developing a common set of vehicle and fuel standards as a means for lowering mobile source air emissions. There are major questions that have already been raised on whether California vehicle standards can be used without California gasoline standards (as proposed by New York State). In addition, there are major concerns on whether the refining industry can respond to this regionalization of product specifications in what had been a nearly unified market. State and Regional Opt-ins, as they are commonly referred to, can drastically change the demands on the U.S. refining industry.

Analytic Task: Examine the impacts of the Ozone Transport Region on demand for oxygenates in reformulated gasoline and on the use of alternative fuels in flexible fuel/dedicated fuel vehicles in the period 1995 - 2000. Also examine in detail the impacts of wide-spread opt-ins on cost and availability of reformulated fuels in the period 1995 - 2000.

7.2 *Clean Fuel Vehicle Fleets*

The 1992 Energy Policy Act and the 1990 Clean Air Act Amendments both mandate the introduction of "clean fuel" vehicles into centrally-fueled fleets during the period 1995 - 2000. The federal government is now implementing an aggressive program of purchasing alternative fuel vehicles, as are several state governments. The 1990 CAAA also requires that a certain percentage of the vehicles sold in California, starting in 1996, be low emissions, ultra low emissions, or zero emissions vehicles. This approach is being considered by other states, including the ten members of the Ozone Transport Region.

The purchase and operation of these vehicles will, over time, alter the fuel mix of the country. While the initial quantities of vehicles will be small (relative to the total U.S. fleet), they will compete with refiners and blenders for available quantities of feedstocks such as ethanol, methanol, and natural gas. This will be particularly important for ethanol, which has a relatively limited production capacity.

Analytic Task: Examine the impacts of growing alternative fuel vehicle fleets on the demand for ethanol, methanol, reformulated gasoline, and the major blending ethers. This will require setting up separate PADD by PADD alternative vehicle fleet modules, which will then generate fuel demand functions that will be integrated with those of the U.S. refinery sector.

7.3 *Oxygen Content, RVP Ceilings and the Demand for Fuel Additives and Blending Stock*

Tailpipe NO_x emissions, which were initially not a central consideration in the reformulation of gasoline, now are a major source of debate, since NO_x emissions tend to increase with the addition of oxygenates. Shortly, EPA will be determining the maximum level allowed in gasoline for each form of oxygenate for different attainment and non-attainment areas. This will have a major impact on ethanol, primarily, although ceilings on the percentage of amyl and butyl ethers could also cause serious problems for blenders.

A second issue is the 1.0 psi RVP waiver which gasohol has traditionally received. This waiver has become increasing controversial, on the grounds that it contributes to increased ground level ozone (due to evaporative and running losses from the more volatile gasoline) and NO_x emissions. EPA will be deciding, in mid-December, 1993, on the treatment of future ethanol blends in terms of RVP ceilings. If, as expected, EPA develops a compromise that allows certain regions but not others to continue to use ethanol for gasoline blending (but only up to an agreed upon market share), then this will have a major and immediate impact on where ethanol will be used and the level of demand.

Analytic Task: Integrate the December 15, 1993 ethanol RVP decision into the PADD modules for those portions of the country affected by the decision.

7.4 *Linking REFORMGAS to Emissions Models*

In order to examine the potential emissions impacts of fuel choices and public policy choices (i.e., ride sharing or vehicle scrappage in individual State Implementation Plans under the 1990 CAAA), the U.S. EPA has developed a series of models that predict levels of mobile source emissions, based on such variables as the vehicle fleet, the average miles driven, and the average speed during different times of day. These models -- the latest authorized version is the MOBILE 5(a) version -- treat the fuel composition as an exogenous input allowing either Phase I or II Federal RFG and a user-specified oxygen level and market share. Some freedom is provided for O_2 levels in winter scenario runs but MOBILE5(a) will override such inputs if Federal RFG and summer time scenarios are specified concurrently. REFORMGAS, on the other hand, develops relatively complete slates of the lowest cost set of gasoline blending components for any given set of environmental constraints, oil prices, and fuel/additive production capacities. If the output of REFORMGAS could be linked to the input structure for the MOBILE 5(a) model, then proposed public policy initiatives could be examined not only for the demands for fuel components that they generate (barrels of ethanol or ETBE required), but also for the changes in emissions that would result. This would enable DOE and NREL decision-makers to rapidly assess the air emissions impacts of proposed alternative initiatives and to pass this information on to decision-makers.

Analytic Task: To build an analytic linkage that takes REFORMGAS output and puts it into a form that can be read as input for the MOBILE 5(a) model. This will requre a major effort, particularly on the MOBILE 5(a) side, since the data is only accepted by the model in very particular forms (and the model has been deliberately set up to prevent alterations to the basic underlying computations of emissions levels).

APPENDICES

APPENDICES

Appendix A: PADD II REFORMGAS Model runs for 1995 Base Case, 1995 Simple Option, and 1998 Complex Option

Appendix B: PADD III REFORMGAS Model runs for 1995 Simple Option and 1998 Complex Option

Appendix C: Sensitivity Analyses on the Impacts of Opt-ins to California Standards in PADDs II and III

Appendix D: Sensitivity Analyses of the Impacts on PADDs II and III of Changes in the Level of Federal Ethanol Subsidy and in the Allowable RVP for Gasohol Blends under different CAAA Scenarios

Appendix E: Shadow Price Tables for all REFORMGAS Model runs (Base Case, Simple Option, Complex Option, California Standards, and Winter Opt-in)

APPENDIX A:

PADD II REFORMGAS Model runs with Ethanol Subsidy for 1995 Base Case, 1995 Simple Option, and 1998 Complex Option

Table A.1: PADD II Demand for Ethanol, and Ethanol- and Methanol-based Ethers; With Ethanol Subsidy

Component	(barrels per day)		
	Summer Base Case	**Summer Simple Option**	**Summer Complex Option**
Ethanol	500	23,061	500
ETBE	0	22,500	27,500
TAEE	0	0	0
MTBE	40,000	40,000	40,000
TAME	1,000	5,000	10,000
All Oxygenates	41,500	90,561	78,000
Gasoline	2,362,187	2,362,187	2,433,585

Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.22	$34.24	$29.74	$30.03	$30.53	$29.58	$24.69	$31.25	$29.68	$30.69
Lower Bound	75,000	50,000	75,000	100,000	100,000	65,000	5,000	0	0	200,000
Upper Bound	175,000	175,000	175,000	175,000	225,000	275,000	640,763	500,000	712,500	230,000

Objective Function $ 7.101E+07 = daily cost of supply

	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Variable Values (b/d)	75,000	50,000	175,000	175,000	104,050	165,293	78,700	500,000	712,500	230,000

Ethanol subsidy = $0.54

Mixing Values

Benzene	Aromatics	Olefins	Oxygen	RVP
1.00%	27.50%	12.32%	1.05%	8.75

Major Components

Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
41,500	444,342	332	300,000	48,314	230,000	1,212,500	85,200
1.76%	18.81%	0.01%	12.70%	2.05%	9.74%	51.33%	3.61%

Average Cost ($/bbl) $30.06

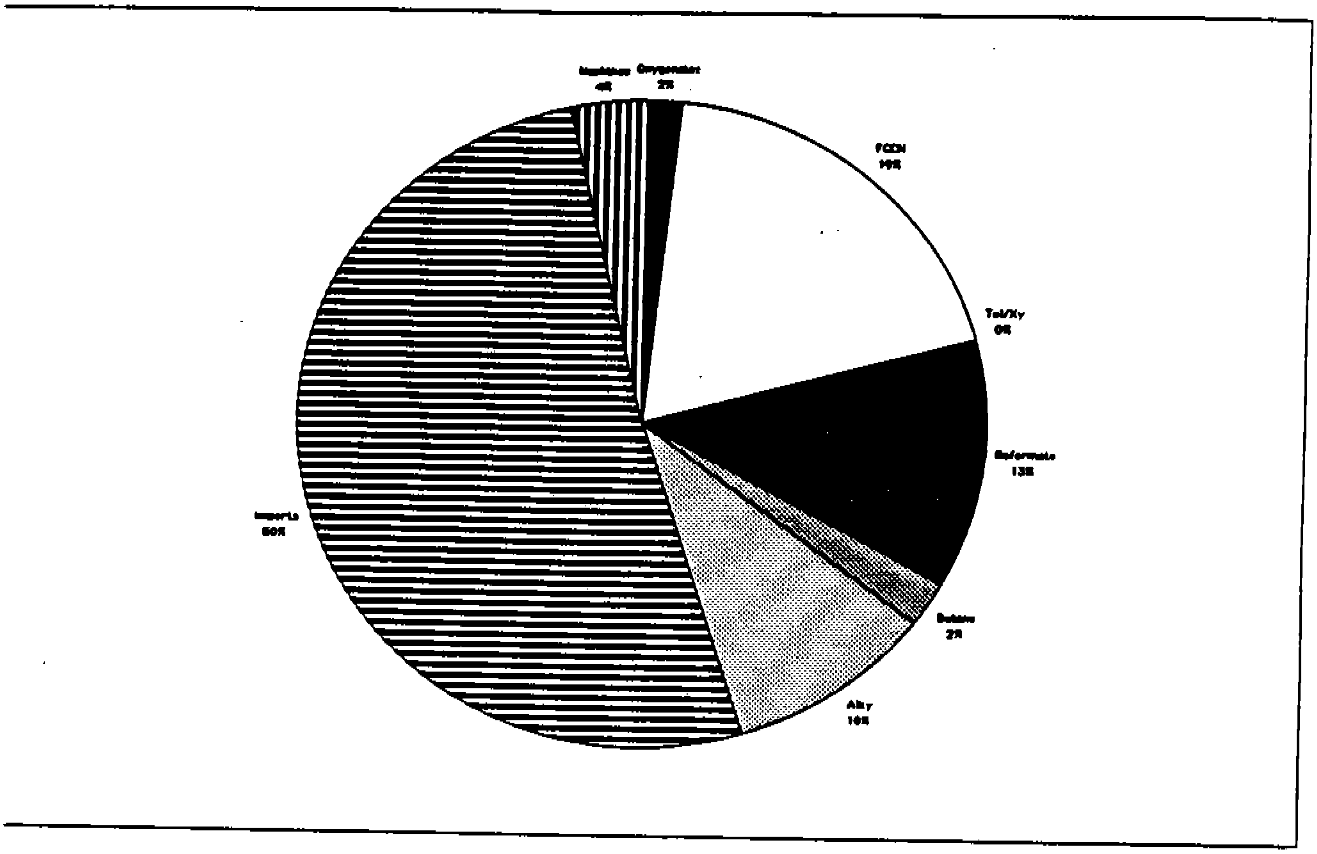
Average cost ($/gal) $0.72

Shadow Prices
($/bbl)

Gasoline	$35.542
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	($5.332)
Oxygen	$0.000
MON	$0.000
RON	$0.306
RVP: Max	($0.308)
I Olefins	$0.000
Benzene	($65.223)
ETOH Prod.	$0.000
MTBE	$1.809
TAME	$0.262
TAEE	$0.000
ETBE	$0.000
Alkylate	($1.760)

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
39.52	$38.36	$39.86	$43.93	$42.80	$18.52	$30.18	$24.07		
00	0	0	0	0	0	0	0	670,500	Lower Bound Total
2,616	40,000	1,000	0	15,000	75,000	7,500	6,500	3,360,879	Upper Bound Total
00	40,000	1,000	0	0	48,314	332	6,500	Mogas Volume 2,362,187	

PADD II Summer Gasoline: 1995 - Current Standards (Base Case)



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.22	$34.34	$29.74	$30.03	$30.53	$29.58	$24.89	$31.25	$29.86	$30.69
Lower Bound	75,000	50,000	75,000	100,000	100,000	65,000	5,000	0	0	200,000
Upper Bound	175,000	175,000	175,000	175,000	225,000	275,000	540,763	437,500	712,500	230,000

Objective Function $ 7.188E+07 = daily cost of supply

	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Variable Values (b/d)	86,110	50,000	175,000	175,000	189,116	82,951	120,989	437,500	712,500	230,000

Ethanol subsidy = $0.54

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	1.00%	25.00%	11.79%	1.49%	8.15

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	90,561	447,067	4,423	311,110	1,536	230,000	1,150,000	127,489
	3.83%	18.93%	0.19%	13.17%	0.07%	9.74%	48.68%	5.40%

Average Cost ($/bbl)
$30.43

Average cost ($/gal)
$0.72

Shadow Prices

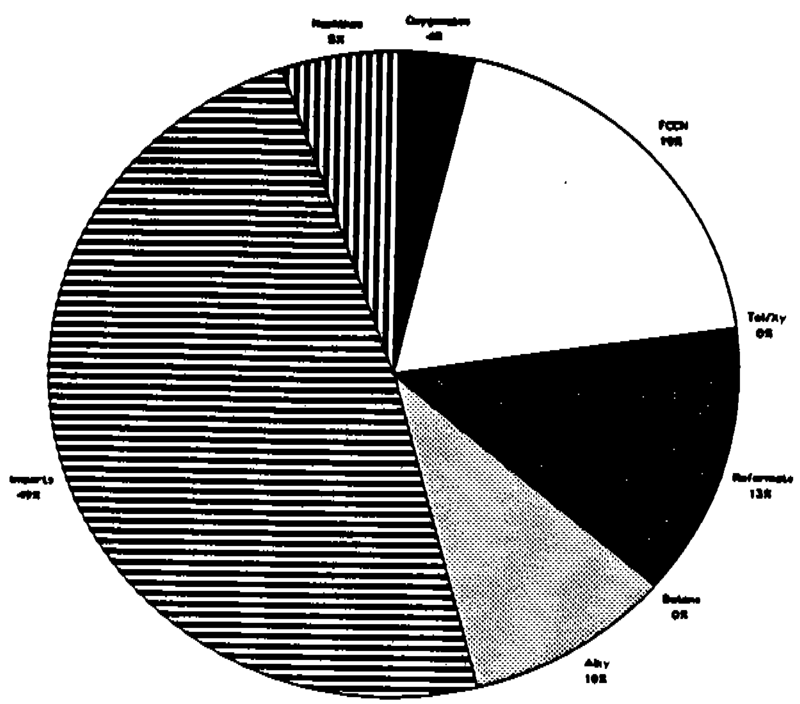
($/bbl)	
asoline	$40.436
CCN	$0.000
eformate	$0.000
lefins	($7.603)
romatics	($9.199)
xygen	$0.000
ON	$0.000
ON	$0.451
VP: Max	($0.396)
t Olefins	$0.000
enzene	($111.538)
TOH Prod.	($1.184)
TBE	$9.364
AME	$7.452
AEE	$0.661
TBE	$6.832
lkylate	$5.114

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap
$39.52	$36.26	$39.86	$43.93	$42.80	$18.52	$30.18	$24.07
500	0	0	0	0	100	100	0
32,616	40,000	5,000	0	22,500	75,000	7,500	8,500
23,061	40,000	5,000	0	22,500	1,536	4,423	6,500

670,700 Lower Bound Total
3,309,679 Upper Bound Total

Mogas Volume
2,362,187

PADD II Summer Gasoline: 1995 - Simple Option



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.22	$34.34	$29.74	$30.03	$30.53	$29.56	$24.69	$31.25	$29.68	$30.69
Lower Bound	75,000	50,000	75,000	100,000	100,000	65,000	5,000	0	0	200,000
Upper Bound	175,000	175,000	175,000	175,000	225,000	275,000	540,763	425,000	712,500	225,000

Objective Function $ 7.356E+07 = daily cost of supply

Variable Values (b/d)	175,000	50,000	175,000	175,000	110,743	139,939	128,686	425,000	712,500	225,000

Ethanol subsidy = $0.54

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	1.00%	25.67%	11.22%	1.19%	8.13

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	78,000	425,681	0	400,000	32,217	225,000	1,137,500	135,186
	3.21%	17.49%	0.00%	16.44%	1.32%	9.25%	46.74%	5.56%

Average Cost ($/bbl) $30.23
Average cost ($/gal) $0.72

Shadow Prices

	($/bbl)
Gasoline	$41.335
FCCN	$0.000
Reformate	$0.210
Olefins	($0.416)
Aromatics	$0.000
Oxygen	$0.000
RON	$0.000
MON	$0.210
RVP: Max	($0.416)
Olefins	$0.000
Benzene	($511.733)
ETOH Prod.	$0.000
MTBE	$4.554
TAME	$4.206
TAEE	$0.000
ETBE	$2.117
Alkylate	$4.802

APPENDIX B:

PADD III REFORMGAS Model runs with Ethanol Subsidy for 1995 Simple Option and 1998 Complex Option

Table B.1: PADD III Demand for Ethanol, and Ethanol- and Methanol-based Ethers; With Ethanol Subsidy			
Component	**(barrels per day)**		
	Summer Base Case	**Summer Simple Option**	**Summer Complex Option**
Ethanol	3,690	500	100
ETBE	37,500	30,000	38,000
TAEE	0	17,500	28,000
MTBE	35,000	40,000	40,000
TAME	37,500	25,000	27,500
All Oxygenates	113,690	113,000	133,600
Gasoline	1,187,000	1,187,000	1,187,000

Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.24	$34.47	$29.85	$30.15	$30.85	$29.70	$24.60	$31.45	$29.88	$30.69
Lower Bound	75,000	25,000	225,000	125,000	75,000	50,000	5,000	0	0	50,000
Upper Bound	110,000	50,000	300,000	225,000	125,000	75,000	1,132,382	125,000	25,000	230,000
Objective Function		$ 3.662E+07	= daily cost of supply							
Variable Values (b/d)	75,000	25,000	243,931	125,000	75,000	50,000	23,734	105,578	0	230,000
Ethanol subsidy =	$0.54									

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	1.00%	22.52%	9.32%	1.65%	7.90

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	113,000	250,000	100	343,931	812	230,000	105,578	143,579
	9.52%	21.06%	0.01%	28.97%	0.07%	19.38%	8.89%	12.10%

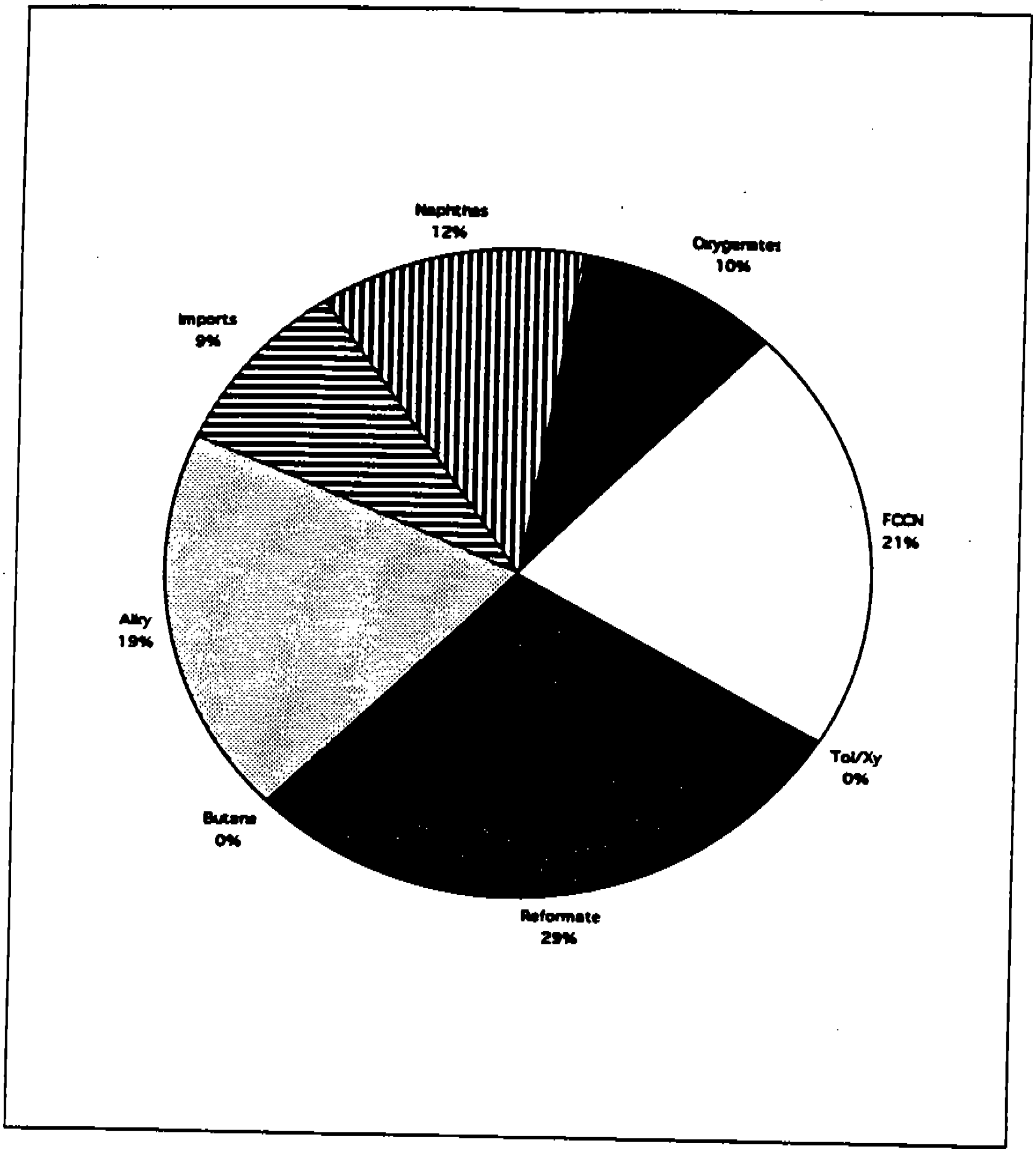
Average Cost ($/bbl)
$30.76
Average cost ($/gal)
$0.73

Shadow Prices
($/bbl)

Gasoline	($45.013)
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	($12.867)
Oxygen	$0.000
MON	$0.000
RON	$0.000
RVP: Max	($0.475)
Lt Olefins	$0.000
Benzene	($914.641)
ETOH Prod.	$0.000
MTBE	$2.946
TAME	$4.203
TAEE	$0.613
ETBE	$0.317
Alkylate	$5.672

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$39.52	$36.36	$39.86	$43.92	$42.79	$16.52	$30.39	$24.07		
500	0	0	0	0	100	100	0	630,700	Lower Bound Total
11,416	40,000	25,000	17,500	30,000	25,000	7,500	119,845	2,673,643	Upper Bound Total
								Mogas Volume	
500	40,000	25,000	17,500	30,000	612	100	119,845	1,167,000	

PADD III Summer Gasoline: 1995 - Simple Option



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.34	$34.47	$29.85	$30.15	$30.65	$29.70	$24.69	$31.45	$29.86	$30.69
Lower Bound	50,000	50,000	82,500	50,000	50,000	50,000	5,000	0	0	50,000
Upper Bound	150,000	175,000	180,000	175,000	125,000	175,000	1,132,382	125,000	25,000	260,000

Objective Function $ 3.698E+07 = daily cost of supply

Variable Values (b/d)	50,000	50,000	82,500	175,000	88,543	82,893	83,091	120,715	0	260,000

Ethanol subsidy = $0.54

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	1.00%	22.50%	11.06%	2.06%	7.48

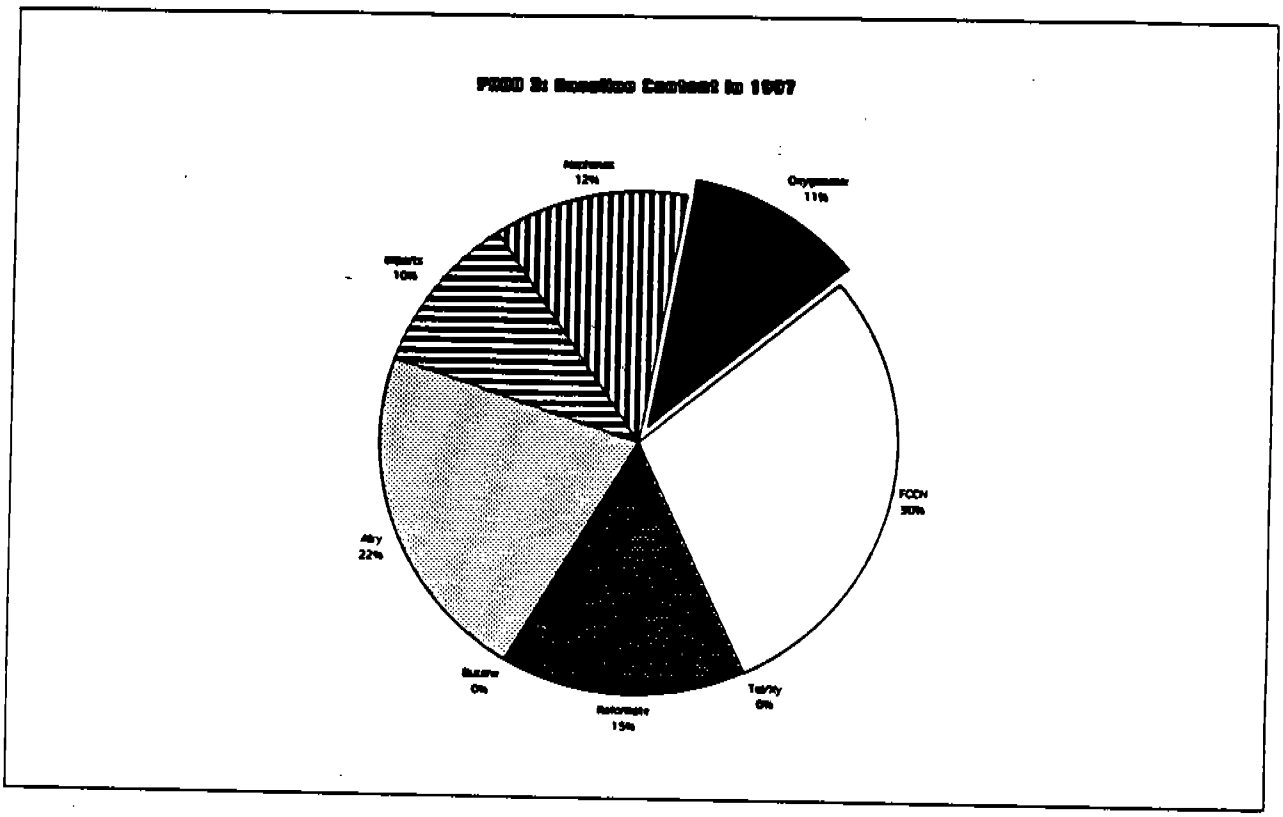
Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	133,600	346,436	0	182,500	0	260,000	120,715	143,749
	11.26%	29.19%	0.00%	15.37%	0.00%	21.90%	10.17%	12.11%

Average Cost ($/bbl)
$31.16
Average cost ($/gal)
$0.74

Shadow Prices
($/bbl)

Gasoline	($81.267)
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	($50.039)
Oxygen	$0.000
MON	$0.000
RON	$0.000
RVP: Max	($3.685)
Lt Olefins	$0.000
Benzene	($590.849)
ETOH Prod.	($36.800)
MTBE	$14.273
TAME	$34.727
TAEE	$34.446
ETBE	$24.222
Alkylate	$17.990

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$39.52	$38.36	$39.86	$43.92	$42.79	$18.52	$30.29	$24.07		
100	0	0	0	0	0	0	0	387,600	Lower Bound Total
13,046	40,000	27,500	28,000	38,000	25,000	7,500	60,658	2,762,087	Upper Bound Total
100	40,000	27,500	28,000	38,000	0	0	60,658	Mogas Volume 1,187,000	



APPENDIX C:

Sensitivity Analyses on the Impacts of Opt-ins to California Standards in PADDs II and III

Table C.1: Impacts of CA Standards on Demand for Ethanol, and Ethanol- and Methanol-based Ethers, PADD II

Component	(barrels per day)			
	Summer Base Case		Summer CA Standards	
	Subsidy	No Subsidy	Subsidy	No Subsidy
Ethanol	500	32,616	27,727	520
ETBE	0	15,000	37,500	37,500
TAEE	0	0	0	14,000
MTBE	40,000	40,000	50,000	50,000
TAME	1,000	1,000	15,000	15,000
All Oxygenates	41,500	88,616	130,227	117,020
Gasoline	2,362,187	2,362,187	2,433,585	2,433,585

Table C.2: Impacts of CA Standards on Demand for Ethanol, and Ethanol- and Methanol-based Ethers, PADD III

Component	(barrels per day)			
	Summer Base Case		Summer CA Standards	
	Subsidy	No Subsidy	Subsidy	No Subsidy
Ethanol	3,690	500	500	500
ETBE	37,500	15,000	42,994	39,392
TAEE	0	0	36,205	40,731
MTBE	35,000	40,000	45,256	45,256
TAME	37,500	1,000	31,114	31,114
All Oxygenates	113,690	56,500	156,069	156,993
Gasoline	1,187,000	1,187,000	1,342,982	1,342,982

Introduction

One of the major potential sources of uncertainty in the U.S. petroleum industry is the issue of which states will chose to exercise their right, under the 1990 CAAA, to "opt-in" to gasoline reformulation standards which are more strict than required. Under the 1990 CAAA, only the worst nine ozone non-attainment areas are required to use reformulated gasoline. However, any state with a marginal, moderate, serious, or severe nonattainment area can "opt-in" to the federal reformulated gasoline program.

In 1992 - 1993, one of the contentious issues that arose as states developed and made public their state implementation plans was that several states (Kentucky is definite and Missouri and Ohio are actively considering) have announced their intention to opt-in to reformulated gasoline. If a number of major states adopt these standards even though they are not required to, it will impose additional demands on the refining sector. The ultimate example would be for a significant opt-in level to California specification gasoline, which has more strict formulation requirements than the federal standards imposed by the 1990 CAAA.[1] To test the implications of this option, we have examined in PADD II and III the impacts of limited and extensive opt-in of non-attainment areas to California specification gasoline. The results of these runs are shown in the tables that follow.

However, it should be emphasized that these results cannot be compared with any of the other results in this study or in Appendices A, B, and D. This is because the **refining portion of the REFORMGAS model** used to reach these results is **not** the same as that used for the other model runs. In simple terms, the refining sector projected by industry for 1995 and 1998 could <u>not</u> produce enough gasoline with California specifications: it was lacking in a number of key components such alkylation and isomerization capacity. There was no feasible solution, given the production capacity for various gasoline components. To meet the projected California specification gasoline demand and to get feasible solutions, the refining sector in the REFORMGAS model had to be severely overhauled, so that it produced a very different refining slate. Among other things, a great deal of volatile organic compounds had to be removed from the base gasoline, and aromatics and olefins transformed into other products. This is very expensive but technically feasible. This means, among other things, that this "new" base gasoline will be more expensive, that it will be deficient in octane, and that it will have far less aromatics and olefins content than of the base gasoline required for federal reformulated gasoline.

This explains why there suddenly appears, in the high opt-in to CA standards scenarios, some summertime demand for ethanol as a blendstock in gasohol. With many of the objectionable compounds in the refinery slate removed in the refining process, there is now the possibility of adding in ethanol, as an octane enhancer and source of oxygenate, without

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[1] New York and the other East Coast states that comprise the Ozone Transport Region announced their intention to opt-in to reformulated gasoline, but **to also adopt the California vehicle fleet program <u>without</u> California gasoline specifications, effective in 1995 or 1996.** This approach has been challenged by the American Automobile Manufacturers Association, on the grounds that the California vehicles must be mated with California specification gasoline.

exceeding RVP or VOC ceilings. The level of ethanol use (both as gasohol blendstock and as feedstock for the creation of ETBE and TAEE) is somewhat dependent on ethanol price, but much more sensitive to changes in the allowable RVP level for gasohol.

Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.84	$35.03	$30.33	$30.03	$30.53	$29.58	$24.69	$33.79	$32.11	$31.44
Lower Bound	75,000	50,000	75,000	100,000	100,000	65,000	5,000	0	0	200,000
Upper Bound	175,000	175,000	225,000	175,000	225,000	275,000	540,763	437,500	712,500	225,000

Objective Function $ 7.793E+07 = daily cost of supply

Variable Values (b/d)	83,811	94,307	225,000	175,000	113,897	65,000	189,714	437,500	712,500	211,061

Ethanol subsidy = $0.00

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	1.00%	23.78%	10.00%	1.45%	7.52

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	117,020	353,897	2,275	403,118	0	211,061	1,150,000	196,214
	4.81%	14.54%	0.09%	16.56%	0.00%	8.67%	47.26%	8.06%

Average Cost ($/bbl) $32.02

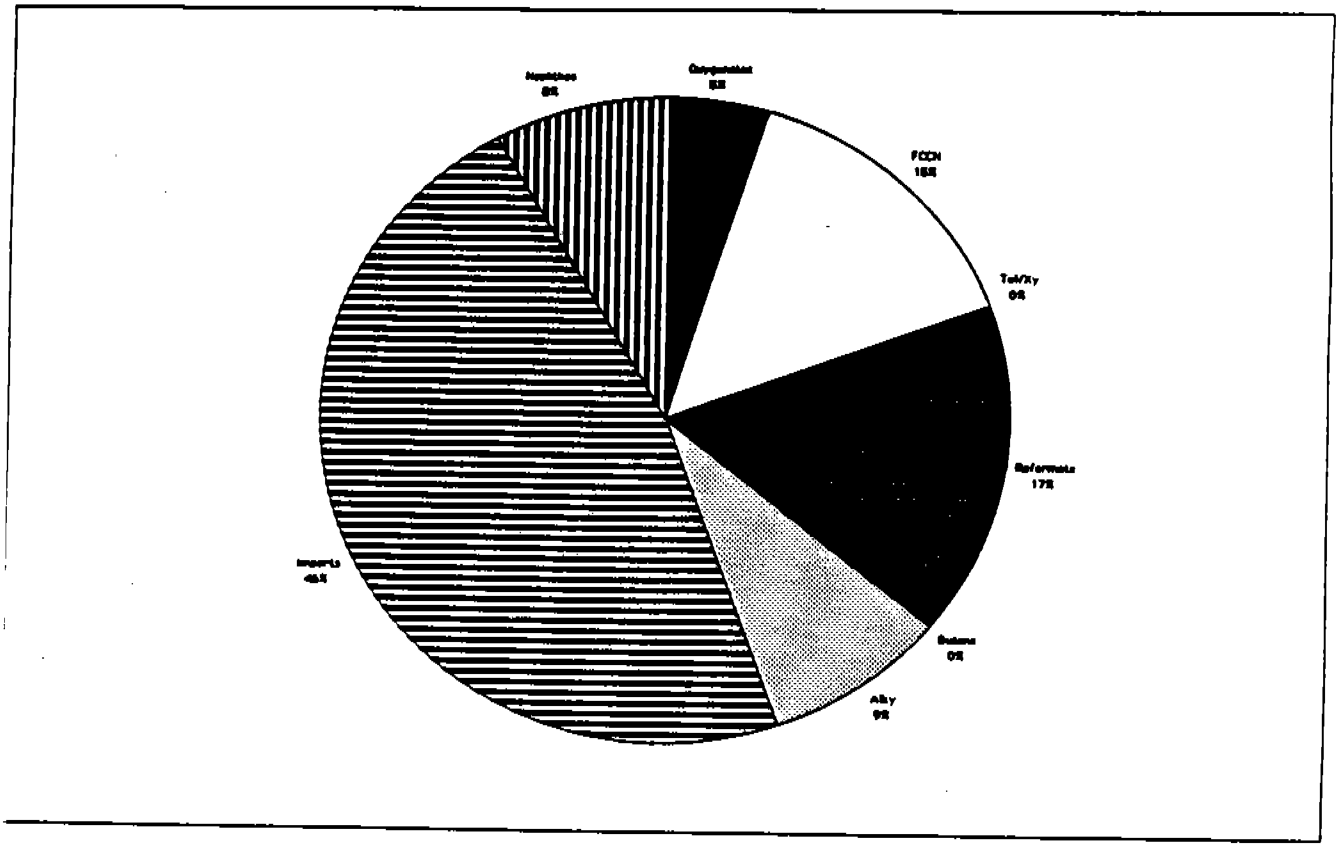
Average cost ($/gal) $0.76

Shadow Prices

($/bbl)	
Gasoline	$64.034
FCCN	$0.000
Reformate	$0.000
Olefins	($45.992)
Aromatics	($41.751)
Oxygen	$0.000
MON	$0.000
RON	$1.210
RVP: Max	($0.859)
Lt Olefins	($17.744)
Benzene	($162.138)
ETOH Prod.	$0.000
MTBE	$31.901
TAME	$31.447
TAEE	$14.185
ETBE	$26.729
Alkylate	$0.000

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$58.80	$39.30	$40.80	$51.66	$51.97	$18.52	$30.78	$24.07		
500	0	0	0	0	0	0	0	670,500	Lower Bound Total
32,616	50,000	15,000	14,000	37,500	75,000	7,500	6,500	3,403,879	Upper Bound Total
								Mogas Volume	
520	50,000	15,000	14,000	37,500	0	2,275	6,500	2,433,565	

PADD II Summer Gasoline: 1998 - Complex Option (CA Standards)



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.84	$35.03	$30.33	$30.03	$30.53	$29.58	$24.69	$33.79	$32.11	$31.44
Lower Bound	75,000	50,000	75,000	100,000	100,000	65,000	5,000	0	0	200,000
Upper Bound	175,000	175,000	225,000	175,000	225,000	275,000	540,763	437,500	712,500	225,000

Objective Function $ 7.739E+07 = daily cost of supply

Variable Values (b/d)	75,000	50,000	225,000	141,364	100,000	157,468	166,251	437,500	712,500	225,000

Ethanol subsidy = $0.54

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	1.00%	23.78%	10.00%	1.75%	7.62

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	130,227	398,832	3,414	350,000	3,361	225,000	1,150,000	172,751
	5.35%	16.39%	0.14%	14.38%	0.14%	9.25%	47.28%	7.10%

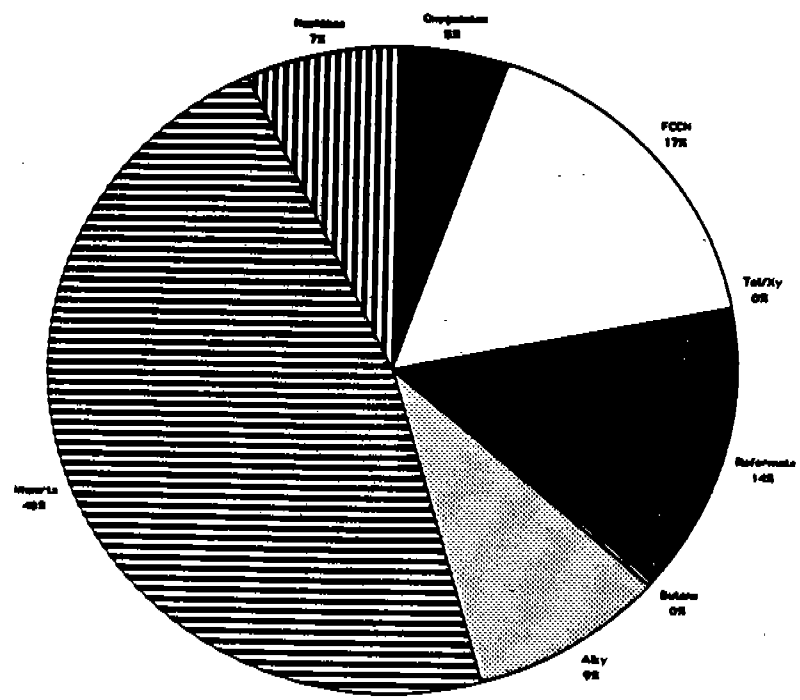
Average Cost ($/bbl)
$31.80
Average cost ($/gal)
$0.76

Shadow Prices
($/bbl)

Gasoline	$0.000
FCCN	$0.000
Reformate	($7.080)
Olefins	($7.895)
Aromatics	$39.365
Oxygen	$0.000
RON	$0.000
MON	$0.421
RVP: Max	($0.377)
Olefins	$0.000
Benzene	($99.652)
ETOH Prod.	$0.000
MTBE	$6.818
TAME	$4.976
ETEE	$0.000
ETBE	$4.611
Alkylate	$3.597

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$39.52	$39.30	$40.80	$44.91	$43.78	$18.52	$30.78	$24.07		
500	0	0	0	0	0	0	0	670,500	Lower Bound Total
32,616	50,000	15,000	14,000	37,500	75,000	7,500	6,500	3,403,879	Upper Bound Total
								Mogas Volume	
27,727	50,000	15,000	0	37,500	3,361	3,414	6,500	2,433,585	

PADD II Summer Gasoline: 1998 - Complex Option (CA Standards)



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.34	$34.47	$29.85	$30.15	$30.65	$29.70	$24.69	$31.45	$29.88	$30.69
Lower Bound	75,000	25,000	225,000	50,000	50,000	50,000	5,000	0	0	50,000
Upper Bound	110,000	50,000	300,000	225,000	125,000	75,000	1,132,382	125,000	25,000	290,000

Objective Function $ 4.251E+07 = daily cost of supply

Variable Values (b/d)	75,000	25,000	225,000	194,627	50,000	75,000	6,416	125,000	0	290,000

Ethanol subsidy = $0.00

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	0.98%	21.97%	9.59%	1.96%	7.43

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	156,993	319,627	0	325,000	100	290,000	125,000	126,261
	11.69%	23.80%	0.00%	24.20%	0.01%	21.59%	9.31%	9.40%

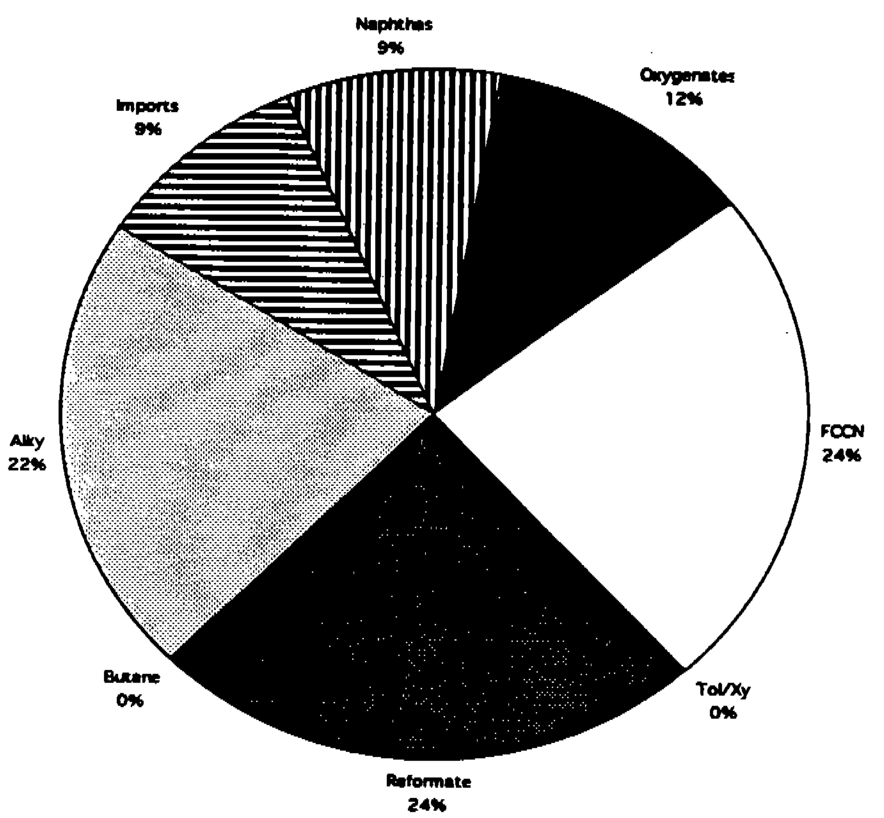
Average Cost ($/bbl)
$31.65
Average cost ($/gal)
$0.75

Shadow Prices
($/bbl)

Gasoline	($62.730)
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	($40.194)
Oxygen	$0.000
MON	$0.000
RON	$0.000
RVP: Max	($2.936)
Lt Olefins	$0.000
Benzene	$0.000
ETOH Prod.	($63.583)
MTBE	$1.472
TAME	$16.999
TAEE	$0.000
ETBE	$0.000
Alkylate	$8.417

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$58.80	$38.36	$39.86	$50.67	$50.99	$18.52	$30.29	$24.07		
500	0	0	0	0	100	0	0	530,600	Lower Bound Total
17,123	45,256	31,114	40,731	48,651	25,000	7,500	119,845	2,792,602	Upper Bound Total
500	45,256	31,114	40,731	39,392	100	0	119,845	Mogas Volume 1,342,982	

PADD III Summer Gasoline: 1998 - Complex Option



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.34	$34.47	$29.85	$30.15	$30.65	$29.70	$24.69	$31.45	$29.88	$30.69
Lower Bound	75,000	25,000	225,000	50,000	50,000	50,000	5,000	0	0	50,000
Upper Bound	110,000	50,000	300,000	225,000	125,000	75,000	1,132,382	125,000	25,000	290,000
Objective Function		$ 4.202E+07	= daily cost of supply							
Variable Values (b/d)	75,000	25,000	225,000	217,620	50,000	56,961	5,000	125,000	18,219	290,000
Ethanol subsidy =	$0.54									

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	0.97%	21.97%	10.00%	1.96%	7.43

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	156,069	324,581	0	325,000	100	290,000	143,219	104,013
	11.62%	24.17%	0.00%	24.20%	0.01%	21.59%	10.66%	7.74%

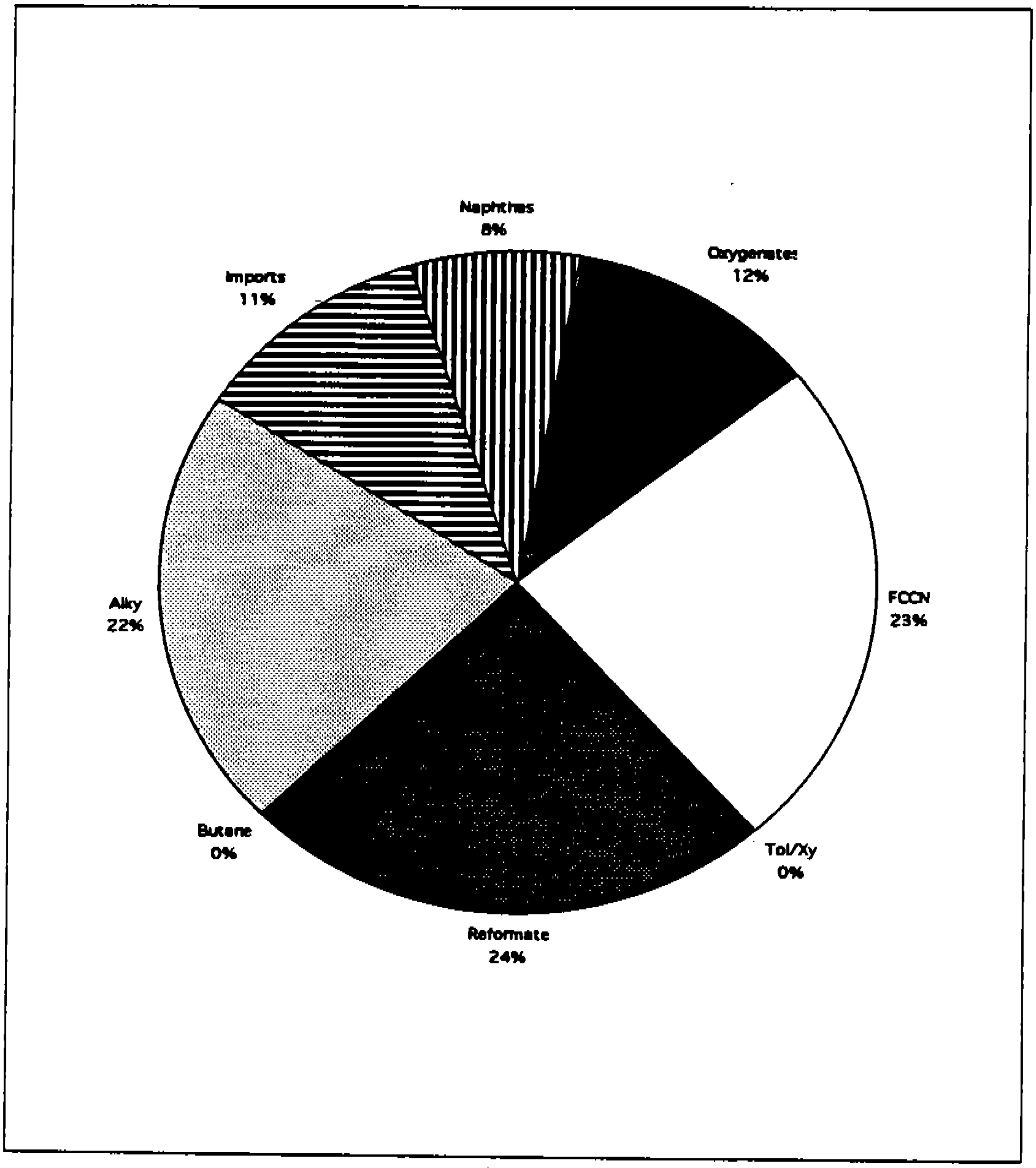
Average Cost ($/bbl)
$31.29
Average cost ($/gal)
$0.75

Shadow Prices
($/bbl)

Gasoline	($257.832)
FCCN	$0.000
Reformate	$0.000
Olefins	($27.781)
Aromatics	($301.314)
Oxygen	$0.000
MON	$0.000
RON	$0.000
RVP: Max	($19.946)
Lt Olefins	$0.000
Benzene	$0.000
ETOH Prod.	($30.985)
MTBE	$73.896
TAME	$188.061
TAEE	$203.962
ETBE	$145.255
Alkylate	$74.110

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$39.52	$38.36	$39.86	$43.92	$42.79	$18.52	$30.29	$24.07		
500	0	0	0	0	100	0	0	530,600	Lower Bound Total
16,308	45,256	31,114	36,205	42,994	25,000	7,500	119,845	2,781,604	Upper Bound Total
								Mogas Volume	
500	45,256	31,114	36,205	42,994	100	0	99,013	1,342,962	

PADD III Summer Gasoline: 1998 - Complex Option



APPENDIX D:

Sensitivity Analyses of the Impacts on PADDs II and III of Changes in the Level of Federal Ethanol Subsidy and in the Allowable RVP for Gasohol Blends under different CAAA Scenarios

Introduction

Under current federal legislation, gasoline blended with 10% ethanol receives a reduction in the federal highway tax of 5.4 cents per gallon, resulting in an effective tax reduction per gallon of ethanol of $0.54 per gallon. This tax reduction is currently scheduled to continue through the year 2000. In addition, the CAAA specified that gasohol would be given a 1.0 pound per square inch (1.0 psi) waiver in the allowable Reid Vapor Pressure (RVP) in non-attainment areas. This RVP waiver has been a source of great controversy, in part because a number of analysts have maintained that it would lead to an increase in NO_x levels in ozone non-attainment areas, and that the 1990 CAAA specifically forbids any oxygenate levels that contribute to NO_x levels increases.

At this time, there is discussion of possibly proportionately extending the ethanol tax reduction to ethers derived from ethanol (ETBE and TAEE): they would receive a tax reduction on the percentage of the final product that is ethanol. If 42% of the feedstock is ethanol, then the resulting ether would receive 42% of $0.54/gallon or approximately $0.23 per gallon.

In the following model runs, we have examined a number of potential options that are changes from the status quo. In the most extreme case, the highway tax reduction is repealed in 1995 or 1998, as is the RVP waiver. This is indicated below as the **No subsidy, no RVP waiver** case.

What is striking is that eliminating the current subsidy level has surprisingly little impact on the usage of ethanol or ethanol-based ethers (ETBE and TAEE) in several scenarios: it does not decrease dramatically. This is primarily due to the restricted supply of the isobutylenes and isoamylenes required to create butyl and amyl ethers. Because MTBE and TAME are less expensive to manufacture than the ethyl counterparts (even with the $0.54 subsidy for ethanol), REFORMGAS allocates the vast majority of available isobutylenes and isoamylenes to the manufacture of these methanol-based ethers. What is left over is used in the manufacture of ETBE and TAEE in order to meet RVP constraints. These limited quantities of ethyl ethers produced are not sensitive to the price of ethanol. Of course, this assumes that sufficient quantities of ethanol would be produced and sold at the higher unsubsidized level. This would occur only if producers thought that markets would still exist and there is <u>no</u> evidence that they feel so since the ether markets are just beginning to develop.

Eliminating the RVP waiver does have a significant impact on ethanol use. In most non-attainment areas in PADDs II and III, eliminating the RVP waiver make it virtually impossible to blend gasohol and still meet RVP ceilings. As the REFORMGAS printouts show, ethanol for gasohol blending purposes is represented only in nominal 100 or 500 B/D levels, and the model places a very high value on getting rid of this additive because of the RVP penalty. However, ethanol does continue to be used as a summertime feedstock for ETBE and TAEE production, since these products provide a range of needed attributes such as low RVP, high octane, and dilution of volatile organic compounds in the gasoline pool -- and as a wintertime oxygen and octane source so long as the existing federal tax exemption remains.

Since there are no carbon monoxide non-attainment areas in PADD III, there is no real analytic need to examine the impacts of the ethanol subsidy on wintertime PADD III gasoline pool. Therefore, only PADD II REFORMGAS runs have been included for the wintertime.

Summertime Gasoline
NO ETHANOL SUBSIDY

PADD II

Table D.1: PADD II Demand for Ethanol, and Ethanol- and Methanol-based Ethers; Without Ethanol Subsidy			
Component	**(barrels per day)**		
	Summer Base Case	**Summer Simple Option**	**Summer Complex Option**
Ethanol	32,616	772	500
ETBE	15,000	25,000	27,500
TAEE	0	0	0
MTBE	40,000	40,000	40,000
TAME	1,000	5,000	10,000
All Oxygenates	88,616	70,772	78,000
Gasoline	2,362,187	2,362,187	2,433,585

Table D.2: PADD II Demand for Ethanol, and Ethanol- and Methanol-based Ethers; With Ethanol Subsidy			
Component	**(barrels per day)**		
	Summer Base Case	**Summer Simple Option**	**Summer Complex Option**
Ethanol	500	23,061	500
ETBE	0	22,500	27,500
TAEE	0	0	0
MTBE	40,000	40,000	40,000
TAME	1,000	5,000	10,000
All Oxygenates	41,500	90,561	78,000
Gasoline	2,362,187	2,362,187	2,433,585

Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.23	$34.36	$29.74	$30.04	$30.54	$29.59	$24.69	$31.45	$29.88	$30.69
Lower Bound	75,000	50,000	75,000	100,000	100,000	65,000	5,000	0	0	50,000
Upper Bound	175,000	175,000	175,000	175,000	225,000	275,000	280,593	500,000	750,000	230,000

Objective Function $ 7.270E+07 = daily cost of supply

Variable Values (b/d)	75,000	50,000	109,483	175,000	225,000	65,000	111,873	500,000	748,414	175,409

Ethanol subsidy = $0.00

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	0.99%	27.50%	12.72%	1.52%	8.75

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	88,616	465,000	0	234,483	15,461	175,409	1,248,414	134,805
	3.75%	19.69%	0.00%	9.93%	0.65%	7.43%	52.85%	5.71%

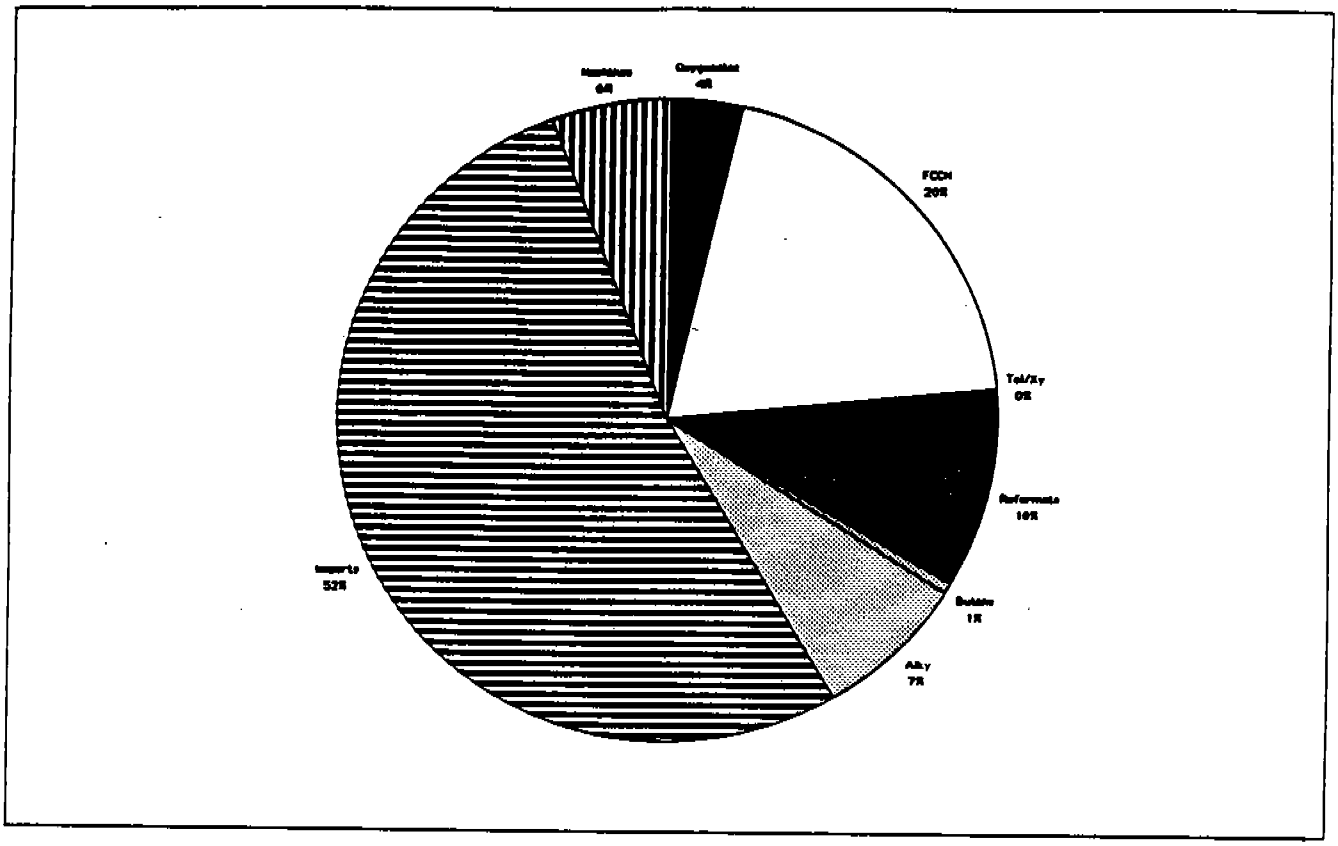
Average Cost ($/bbl)
$30.78
Average cost ($/gal)
$0.73

Shadow Prices

	($/bbl)
Gasoline	($59.791)
FCCN	$0.000
Reformate	$40.869
Olefins	$0.000
Aromatics	$0.000
Oxygen	$0.000
MON	$0.000
RON	$0.566
RVP: Max	($0.424)
Lt Olefins	($11.364)
Benzene	$0.000
ETOH Prod.	($46.242)
MTBE	($20.841)
TAME	($22.811)
TAEE	($31.788)
ETBE	($35.396)
Alkylate	$13.501

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$58.80	$36.36	$39.86	$50.67	$50.99--	$18.52	$30.19	$24.07		
500	0	0	0	0	0	0	0	520,500	Lower Bound Total
32,616	40,000	1,000	0	15,000	75,000	7,500	22,932	3,154,641	Upper Bound Total
								Mogas Volume	
32,616	40,000	1,000	0	15,000	15,461	0	22,932	2,362,187	

PADD II Summer Gasoline: 1995 - Current Standards



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.22	$34.34	$29.74	$30.03	$30.53	$29.58	$24.69	$31.25	$29.68	$30.69
Lower Bound	75,000	50,000	75,000	100,000	100,000	65,000	5,000	0	0	200,000
Upper Bound	175,000	175,000	225,000	175,000	225,000	275,000	540,763	437,500	712,500	230,000

Objective Function $ 7.197E+07 = daily cost of supply

	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Variable Values (b/d)	77,145	58,904	225,000	124,199	225,000	65,000	122,898	437,500	712,500	230,000

Ethanol subsidy = $0.00

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	1.00%	25.00%	11.79%	1.19%	8.13

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	70,772	414,199	6,868	361,050	100	230,000	1,150,000	129,198
	3.00%	17.53%	0.29%	15.28%	0.00%	9.74%	48.68%	5.47%

Average Cost ($/bbl) $30.47

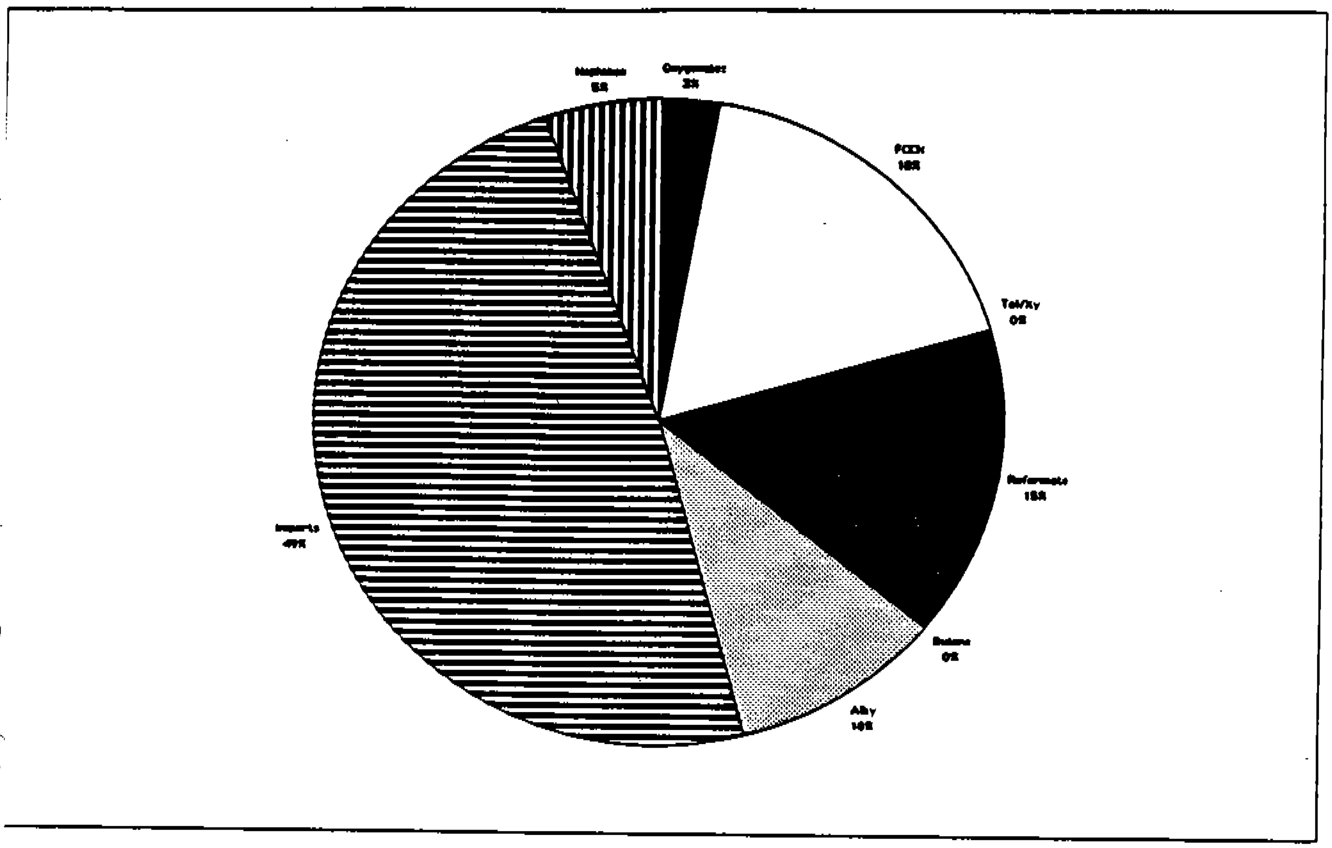
Average cost ($/gal) $0.73

Shadow Prices

	($/bbl)
Gasoline	$64.571
FCCN	$0.000
Reformate	$0.000
Olefins	($43.540)
Aromatics	($43.355)
Oxygen	$0.000
MON	$0.000
RON	$1.221
RVP: Max	($0.882)
Lt Olefins	$0.000
Benzene	($159.962)
ETOH Prod.	$0.000
MTBE	$47.425
TAME	$43.775
TAEE	$26.529
ETBE	$40.628
Alkylate	$21.605

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$56.80	$36.36	$39.86	$50.67	$50.99	$18.52	$30.18	$24.07		
500	0	0	0	0	100	100	0	670,700	Lower Bound Total
32,616	40,000	5,000	0	25,000	75,000	7,600	6,500	3,362,379	Upper Bound Total
								Mogas Volume	
772	40,000	5,000	0	25,000	100	6,868	6,500	2,362,187	

PADD II Summer Gasoline: 1995 - Simple Option



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.22	$34.34	$29.73	$30.03	$30.53	$29.58	$24.69	$31.45	$29.88	$30.69
Lower Bound	75,000	60,000	75,000	100,000	100,000	65,000	5,000	0	0	50,000
Upper Bound	175,000	175,000	175,000	175,000	225,000	275,000	540,763	425,000	712,500	225,000

Objective Function $ 7.453E+07 = daily cost of supply

Variable Values (b/d)	175,000	60,000	175,000	175,000	205,445	90,638	115,501	425,000	712,500	225,000

Ethanol subsidy = $0.00

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	1.00%	25.08%	11.52%	1.10%	8.16

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	78,000	471,084	0	400,000	0	225,000	1,137,500	122,001
	3.21%	19.38%	0.00%	16.44%	0.00%	9.25%	46.74%	5.01%

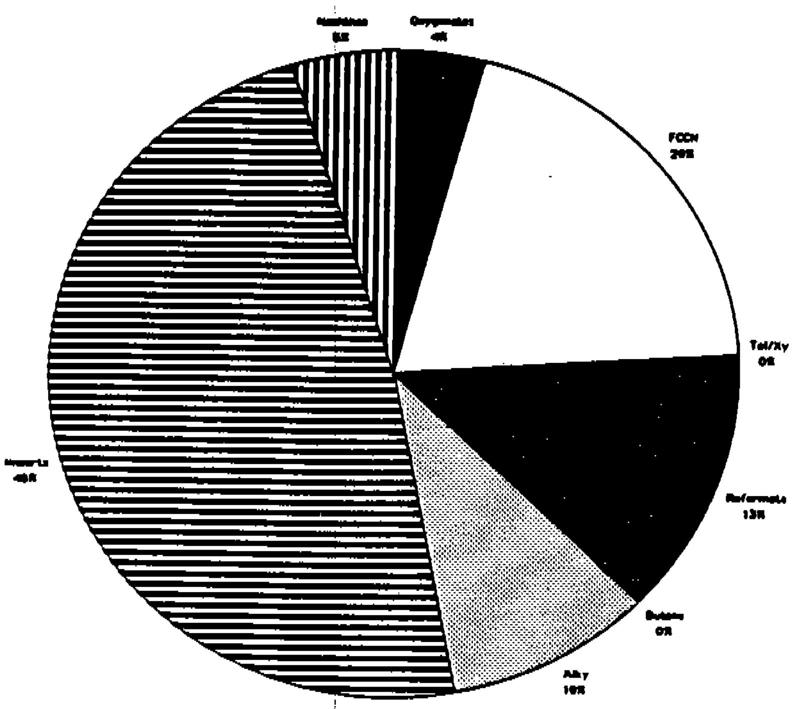
Average Cost ($/bbl)
$30.62
Average cost ($/gal)
$0.73

Shadow Prices

	($/bbl)
Gasoline	$59.010
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	$11.919
Oxygen	$0.000
MON	$0.000
RON	$0.566
RVP: Max	($0.424)
Lt Olefins	$5.693
Benzene	($1,313.110)
ETOH Prod.	$0.000
MTBE	$11.144
TAME	$16.714
TAEE	$7.121
ETBE	$3.148
Alkylate	$0.000

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$58.80	$38.36	$39.86	$50.67	$50.99	$18.52	$30.16	$24.07		
500	0	0	0	0	0	0	0	520,500	Lower Bound Total
32,616	40,000	10,000	0	27,500	75,000	7,500	6,500	3,302,379	Upper Bound Total
								Mogas Volume	
500	40,000	10,000	0	27,500	0	0	6,500	2,433,585	

PADD II Summer Gasoline: 1998 - Complex Option



Summertime Gasoline
NO ETHANOL SUBSIDY

PADD III

Table D.3: PADD III Demand for Ethanol, and Ethanol- and Methanol-based Ethers; Without Ethanol Subsidy

Component	(barrels per day)		
	Summer Base Case	Summer Simple Option	Summer Complex Option
Ethanol	500	500	500
ETBE	15,000	26,146	40,383
TAEE	0	17,500	33,384
MTBE	40,000	40,000	43,076
TAME	1,000	25,000	29,614
All Oxygenates	56,500	109,146	146,957
Gasoline	1,187,000	1,187,000	1,278,269

Table D.4: PADD III Demand for Ethanol, and Ethanol- and Methanol-based Ethers; With Ethanol Subsidy

Component	(barrels per day)		
	Summer Base Case	Summer Simple Option	Summer Complex Option
Ethanol	3,690	500	100
ETBE	37,500	30,000	38,000
TAEE	0	17,500	28,000
MTBE	35,000	40,000	40,000
TAME	37,500	25,000	27,500
All Oxygenates	113,690	113,000	133,600
Gasoline	1,187,000	1,187,000	1,187,000

Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.34	$34.47	$29.85	$30.15	$30.65	$29.70	$24.69	$31.45	$29.88	$30.69
Lower Bound	50,000	50,000	82,500	50,000	50,000	50,000	5,000	0	0	50,000
Upper Bound	150,000	175,000	180,000	175,000	125,000	175,000	1,132,382	125,000	25,000	230,000
Objective Function		$ 3.643E+07	= daily cost of supply							
Variable Values (b/d)	150,000	50,000	180,000	159,975	50,000	50,000	49,867	125,000	25,000	230,000
Ethanol subsidy =	$0.00									

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	1.00%	28.67%	9.51%	1.14%	8.05

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	56,500	259,975	0	380,000	0	230,000	150,000	110,525
	4.76%	21.90%	0.00%	32.01%	0.00%	19.38%	12.64%	9.31%

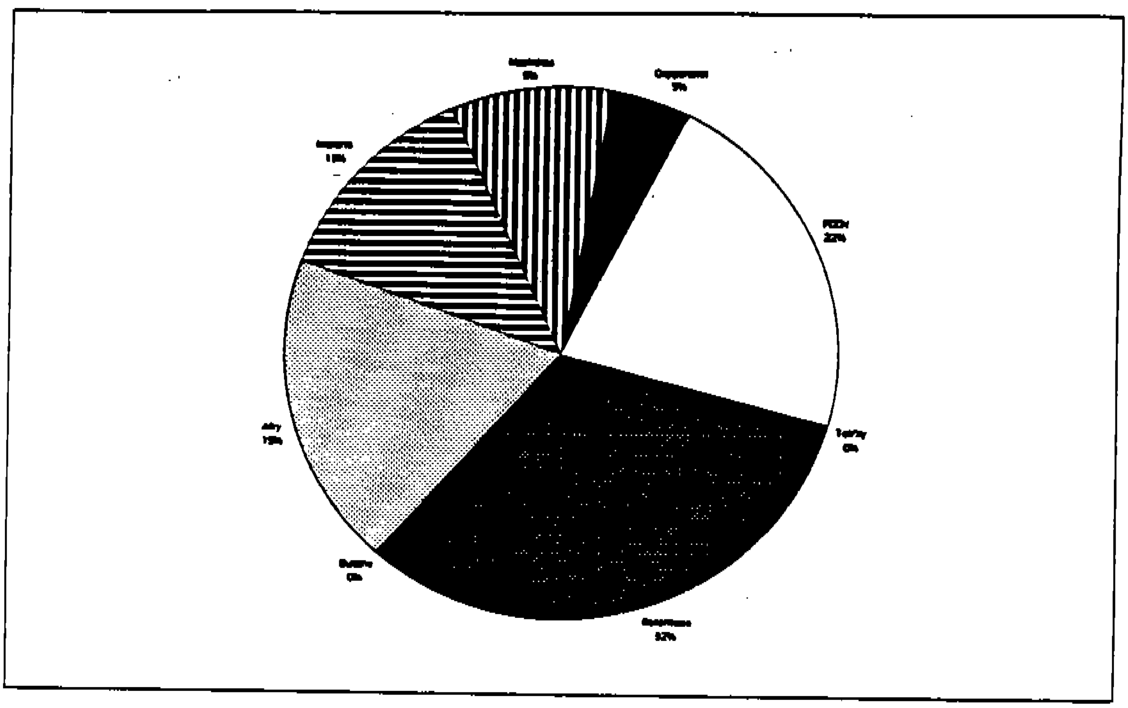
Average Cost ($/bbl)
$30.69
Average cost ($/gal)
$0.73

Shadow Prices
($/bbl)

Gasoline	($59.791)
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	$0.000
Oxygen	$0.000
MON	$0.000
RON	$0.566
RVP: Max	($0.424)
Lt Olefins	$0.000
Benzene	($1,448.501)
ETOH Prod.	$0.000
MTBE	$12.738
TAME	$17.703
TAEE	$8.006
ETBE	$4.346
Alkylate	$13.501

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Crap		
$58.80	$38.36	$39.86	$50.67	$50.99	$18.52	$30.29	$24.07		
500	0	0	0	0	0	0	0	388,000	Lower Bound Total
11,416	40,000	1,000	0	15,000	25,000	7,500	60,658	2,652,956	Upper Bound Total
								Mogas Volume	
500	40,000	1,000	0	15,000	0	0	60,658	1,187,000	

PADD III Summer Gasoline: 1995 - Current Standards



No ETOH Subsidy in Place

Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.24	$34.47	$29.85	$30.15	$30.85	$29.70	$24.69	$31.45	$29.86	$30.69
Lower Bound	75,000	25,000	225,000	125,000	75,000	50,000	5,000	0	0	50,000
Upper Bound	110,000	50,000	300,000	225,000	125,000	75,000	1,132,382	125,000	25,000	230,000

Objective Function $ 3.686E+07 = daily cost of supply

Variable Values (b/d)	75,000	25,000	232,216	125,000	75,000	50,000	19,880	125,000	0	230,000

Ethanol subsidy = $0.00

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	1.00%	22.52%	9.42%	1.61%	7.80

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	109,146	250,000	100	332,216	812	230,000	125,000	139,725
	9.20%	21.06%	0.01%	27.99%	0.07%	19.38%	10.53%	11.77%

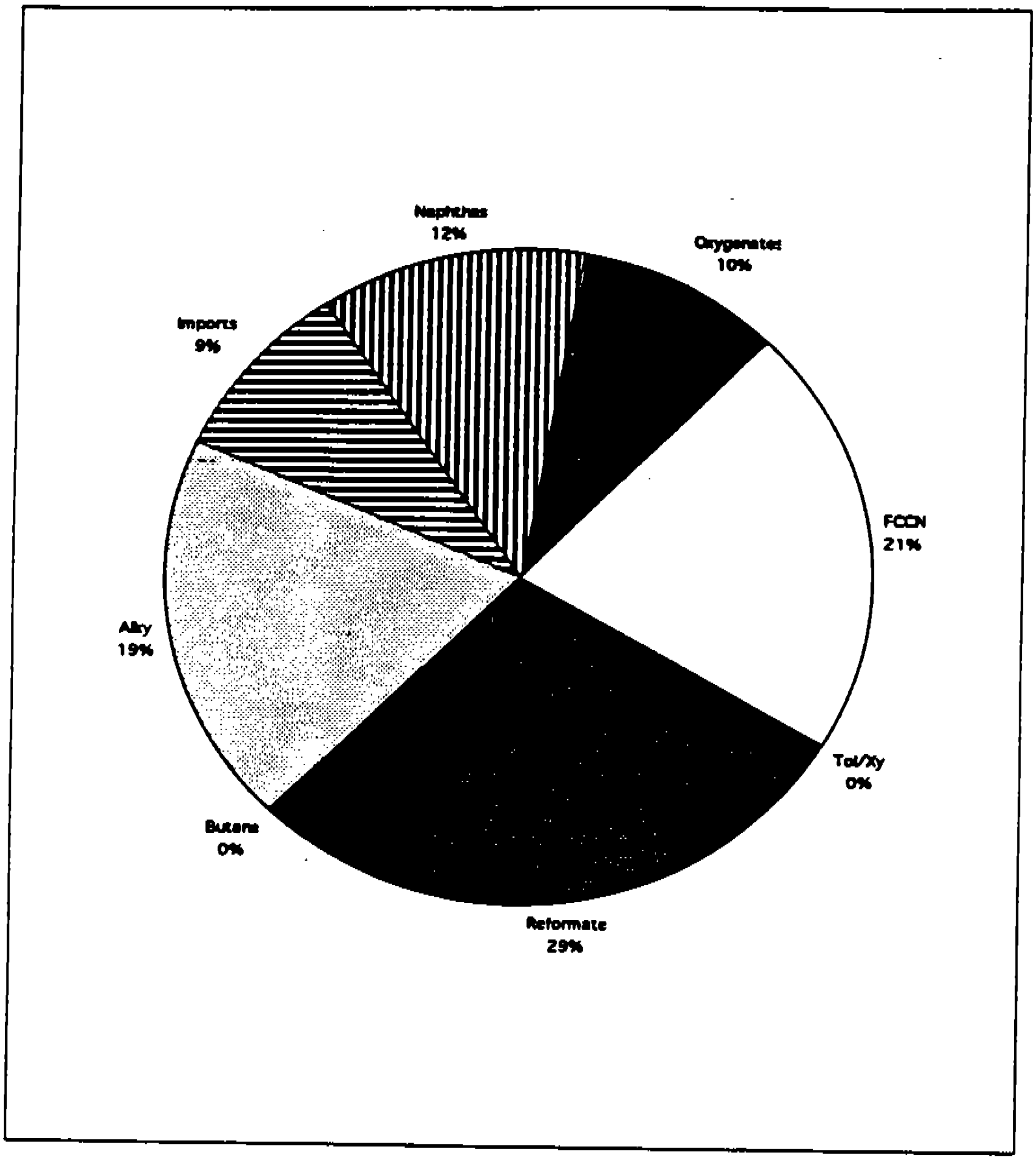
Average Cost ($/bbl)
$31.05
Average cost ($/gal)
$0.74

Shadow Prices
($/bbl)

Gasoline	($53.480)
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	($25.369)
Oxygen	$0.000
MON	$0.000
RON	$0.000
RVP: Max	($0.623)
Lt Olefins	$0.000
Benzene	($1,302.518)
ETOH Prod.	$0.000
MTBE	$10.260
TAME	$12.374
TAEE	$2.185
ETBE	$0.000
Alkylate	$10.591

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$68.80	$38.26	$39.86	$60.67	$60.89	$18.62	$30.29	$24.07		
500	0	0	0	0	100	100	0	630,700	Lower Bound Total
11,416	40,000	25,000	17,800	30,000	25,000	7,500	119,845	2,673,643	Upper Bound Total
								Mogas Volume	
500	40,000	25,000	17,800	26,146	812	100	119,845	1,167,000	

PADD III Summer Gasoline: 1995 - Simple Option



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.34	$34.47	$29.85	$30.15	$30.65	$29.70	$24.69	$31.45	$29.88	$30.69
Lower Bound	75,000	25,000	225,000	50,000	50,000	50,000	5,000	0	0	50,000
Upper Bound	110,000	50,000	300,000	225,000	125,000	75,000	1,132,382	125,000	25,000	250,000
Objective Function		$ 4.044E+07	= daily cost of supply							
Variable Values (b/d)	75,000	25,000	225,000	201,558	50,000	62,854	5,000	125,000	0	250,000
Ethanol subsidy =	$0.00									

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	0.99%	22.52%	9.91%	1.94%	7.48

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	146,957	314,412	0	325,000	100	250,000	125,000	116,800
	11.50%	24.60%	0.00%	25.43%	0.01%	19.56%	9.78%	9.14%

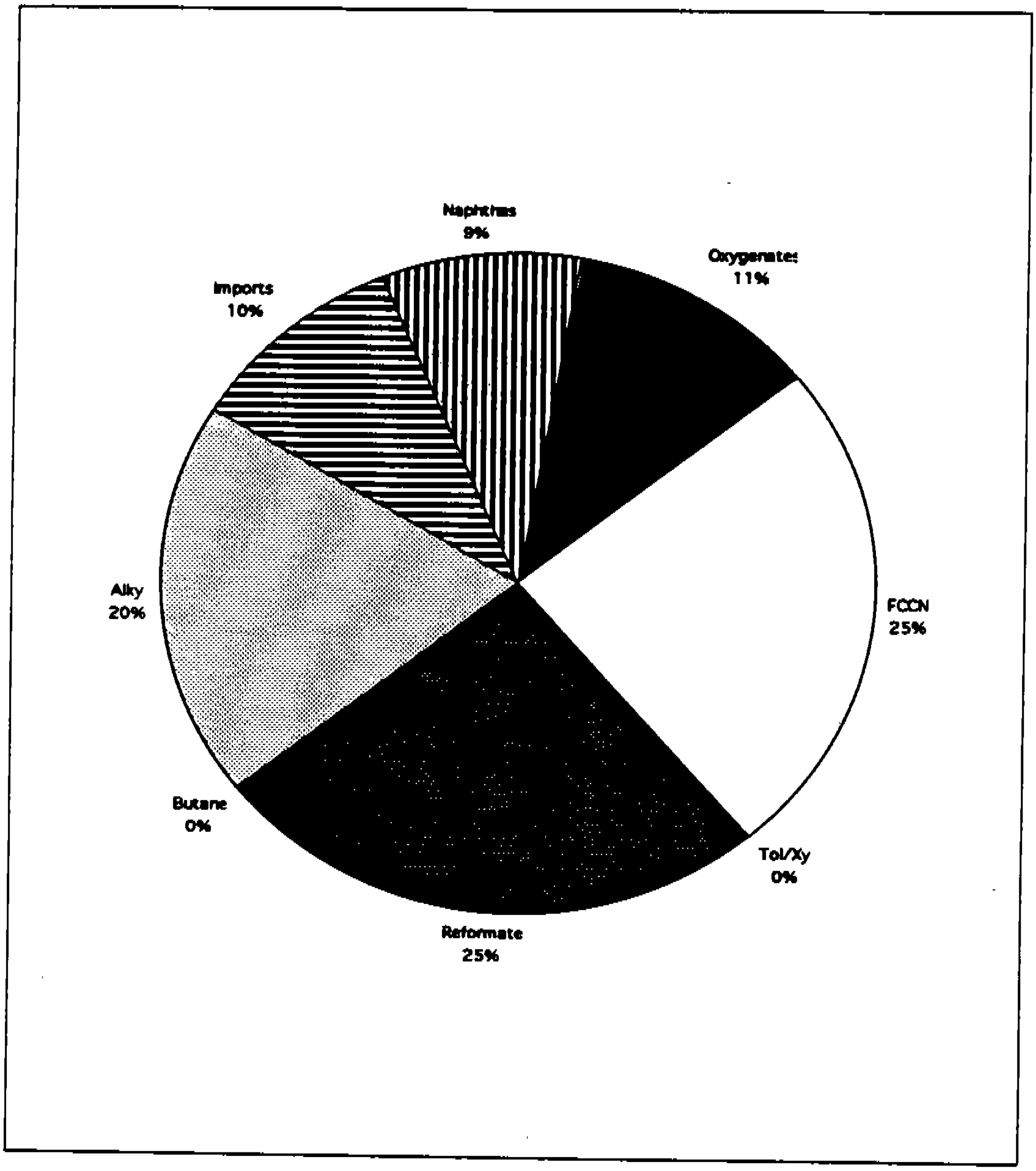
Average Cost ($/bbl)
$31.63
Average cost ($/gal)
$0.75

Shadow Prices
($/bbl)

Gasoline	($114.253)
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	($108.366)
Oxygen	$0.000
MON	$0.000
RON	$0.000
RVP: Max	($7.389)
Lt Olefins	$0.000
Benzene	$0.000
ETOH Prod.	($114.490)
MTBE	$18.261
TAME	$59.616
TAEE	$56.192
ETBE	$33.711
Alkylate	$23.815

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$58.80	$38.36	$39.86	$50.67	$50.99	$18.52	$30.29	$24.07		
500	0	0	0	0	100	0	0	530,600	Lower Bound Total
14,922	43,076	29,614	33,384	40,383	25,000	7,500	119,845	2,731,106	Upper Bound Total
								Mogas Volume	
500	43,076	29,614	33,384	40,383	100	0	111,800	1,278,269	

PADD III Summer Gasoline: 1998 - Complex Option



Wintertime Gasoline
NO ETHANOL SUBSIDY

Wintertime Gasoline
WITH AND WITHOUT ETHANOL SUBSIDY

PADD II

- 1995: Simple Option
- 1998: Complex Option

Table D.5: Impacts of Winter Gasoline on Demand for Ethanol, and Ethanol- and Methanol-based Ethers, PADD II

Component	(barrels per day)			
	Winter Simple Option		Winter Complex Option	
	Subsidy	No Subsidy	Subsidy	No Subsidy
Ethanol	20,348	500	37,508	42,401
ETBE	0	0	35,000	20,133
TAEE	0	0	0	0
MTBE	40,000	40,000	30,000	40,000
TAME	0	0	10,000	10,000
All Oxygenates	60,348	40,500	112,508	112,534
Gasoline	2,362,187	2,362,187	2,433,585	2,433,585

Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.22	$34.84	$29.74	$30.03	$30.63	$28.68	$34.80	$31.25	$29.68	$30.65
Lower Bound	75,000	50,000	75,000	100,000	100,000	65,000	6,000	0	0	200,000
Upper Bound	175,000	175,000	175,000	175,000	225,000	275,000	640,765	425,000	712,500	225,000

Objective Function $ 7.061E+07 = daily cost of supply

	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Variable Values (b/d)	111,114	50,000	175,000	175,000	141,085	106,103	92,037	425,000	712,500	225,000

Ethanol subsidy = $0.54

Mixing Values

Benzene	Aromatics	Olefins	Oxygen	RVP
0.90%	25.96%	11.12%	1.24%	10.62

Major Components

Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
60,348	422,188	7,500	336,114	75,000	225,000	1,137,500	98,537
2.55%	17.87%	0.32%	14.23%	3.18%	9.53%	48.15%	4.17%

Average Cost ($/bbl) $29.86

Average cost ($/gal) $0.71

Shadow Prices
($/bbl)

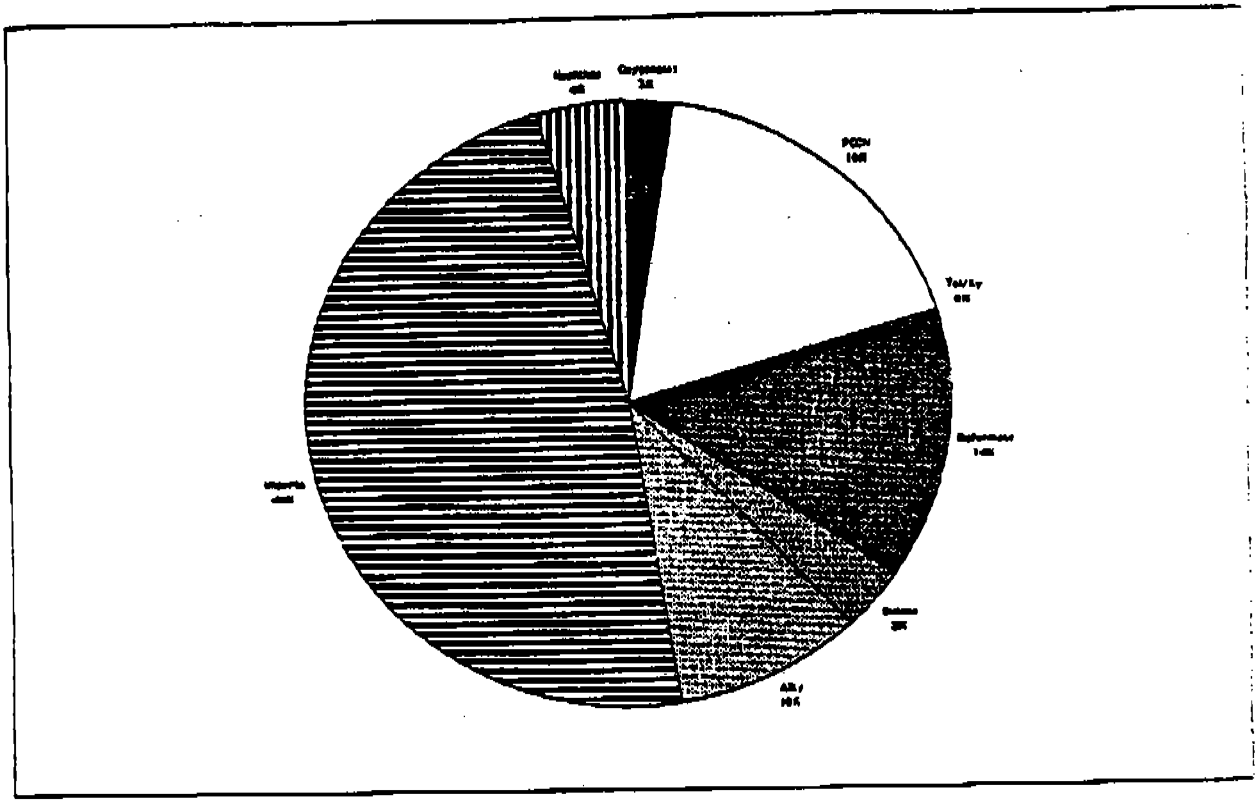
Gasoline	$31.822
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	($2.089)
Oxygen	$13.737
MON	$0.000
RON	$0.335
RVP: Max	($0.035)
Lt Olefins	$0.000
Benzene	$0.000
ETOH Prod.	$0.000
MTBE	$3.207
TAME	$0.000
TAEE	$0.000
ETBE	$0.000
Alkylate	$0.000

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap
$38.62	$38.86	$39.86	$48.93	$42.80	$18.82	$30.18	$24.37
600	0	0	0	0	100	100	0
22,616	40,000	5,000	0	27,800	76,000	7,600	6,500
20,346	40,000	0	0	0	76,000	7,600	6,500

670,700 Lower Bound Total
3,297,379 Upper Bound Total

Mogas Volume
2,362,187

PADD II Winter Gasoline: 1995 - Simple Option



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.22	$34.34	$29.73	$30.03	$30.53	$29.68	$24.69	$31.45	$29.88	$30.69
Lower Bound	75,000	50,000	75,000	100,000	100,000	65,000	5,000	0	0	50,000
Upper Bound	175,000	175,000	175,000	175,000	225,000	275,000	540,763	425,000	712,500	225,000

Objective Function $ 7.090E+07 = daily cost of supply

Variable Values (b/d)	175,000	50,000	175,000	175,000	132,969	90,165	95,280	425,000	712,500	201,773

Ethanol subsidy = $0.00

Mixing Values	Benzene	Aromatics	Olefins	Oxygen	RVP
	1.00%	25.70%	10.58%	0.96%	9.62

Major Components	Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
	40,500	398,134	7,500	400,000	75,000	201,773	1,137,500	101,780
	1.71%	16.85%	0.32%	16.93%	3.18%	8.54%	48.15%	4.31%

Average Cost ($/bbl) $30.02

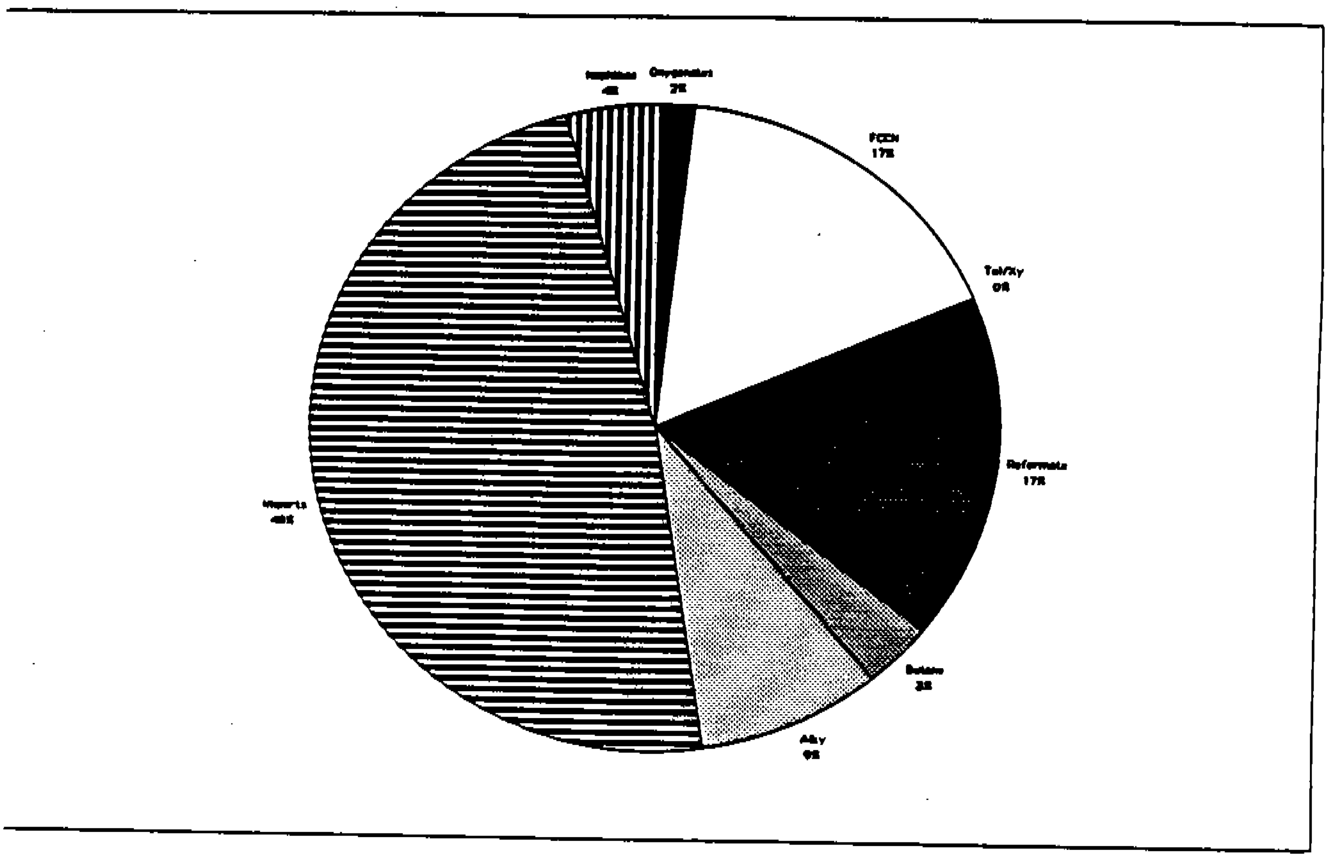
Average cost ($/gal) $0.71

Shadow Prices

($/bbl)	
Gasoline	$31.186
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	$0.000
Oxygen	$0.000
MON	$0.000
RON	$0.566
RVP: Max	($0.424)
Lt Olefins	$0.000
Benzene	$0.286
ETOH Prod.	$0.000
MTBE	$0.000
TAME	$0.449
TAEE	$0.000
ETBE	$0.000
Alkylate	$0.000

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$58.80	$38.36	$39.86	$50.57	$50.99	$18.52	$30.18	$24.07		
500	0	0	0	0	0	0	0	520,500	Lower Bound Total
32,616	40,000	10,000	0	27,500	75,000	7,500	6,500	3,302,379	Upper Bound Total
								Mogas Volume	
500	40,000	0	0	0	75,000	7,500	6,500	2,362,187	

PADD II Winter Gasoline: 1995 - Simple Option



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.22	$34.34	$29.73	$30.03	$30.53	$29.58	$24.89	$32.85	$31.21	$31.44
Lower Bound	75,000	50,000	75,000	100,000	100,000	65,000	5,000	0	0	50,000
Upper Bound	175,000	175,000	175,000	175,000	225,000	275,000	540,763	425,000	712,500	200,000

Objective Function $ 7.518E+07 = daily cost of supply

	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Variable Values (b/d)	151,706	50,000	175,000	100,000	100,000	187,470	155,414	425,000	710,084	179,683

Ethanol subsidy = $0.54

Mixing Values

Benzene	Aromatics	Olefins	Oxygen	RVP
1.00%	25.70%	9.47%	1.68%	10.50

Major Components

Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
112,508	387,470	5,219	376,706	75,000	179,683	1,135,084	161,914
4.62%	15.92%	0.21%	15.48%	3.08%	7.38%	46.64%	6.65%

Average Cost ($/bbl) $30.89

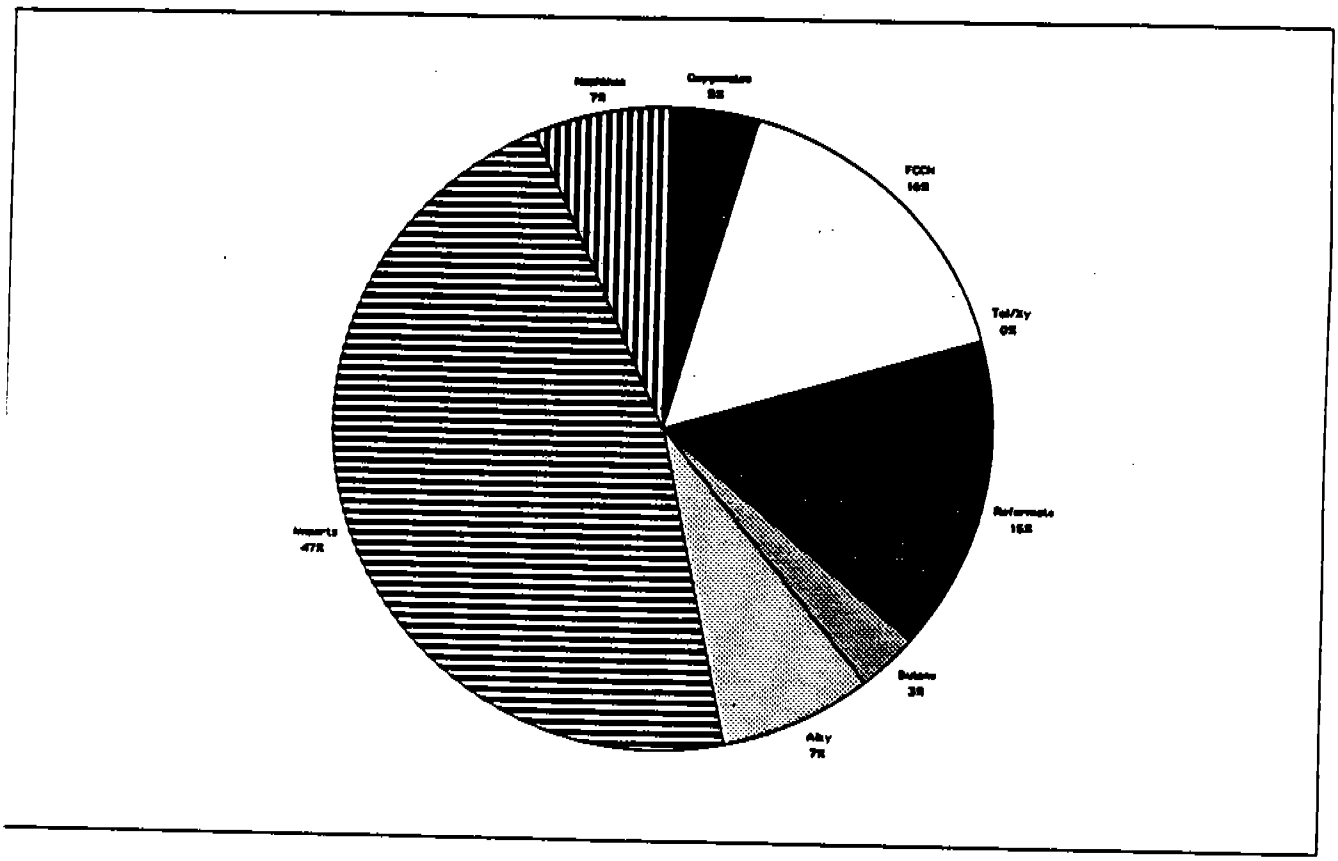
Average cost ($/gal) $0.74

Shadow Prices
($/bbl)

Gasoline	$33.004
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	($1.536)
Oxygen	$111.956
MON	$0.000
RON	$0.295
RVP: Max	($0.115)
Lt Olefins	$0.000
Benzene	($81.549)
ETOH Prod.	$32.435
MTBE	$19.973
TAME	$14.572
TAEE	$6.677
ETBE	$13.721
Alkylate	$0.000

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$39.52	$39.30	$40.80	$44.91	$43.78	$18.52	$30.18	$25.30		
500	0	0	0	0	0	0	0	520,500	Lower Bound Total
37,508	30,000	10,000	0	35,000	75,000	7,500	6,500	3,279,772	Upper Bound Total
								Mogas Volume	
37,508	30,000	10,000	0	35,000	75,000	5,219	6,500	2,433,585	

PADD II Winter Gasoline: 1998 - Complex Option



Simulation Results Summary

Variables	Full Reformate	Heavy Reformate	"LITE" Reformate	Full FCCN	Light FCCN	Heavy FCCN	SR Naphtha	IG-1	IG-2	Alky-Poly
Price ($/bbl)	$31.22	$34.34	$29.73	$30.03	$30.53	$29.58	$24.69	$32.85	$31.21	$31.44
Lower Bound	75,000	50,000	75,000	100,000	100,000	65,000	5,000	0	0	50,000
Upper Bound	175,000	175,000	175,000	175,000	225,000	275,000	540,763	425,000	712,500	200,000

Objective Function $ 7.601E+07 = daily cost of supply

Variable Values (b/d)	175,000	50,000	175,000	175,000	114,445	168.102	158,664	425,000	595,149	200.000

Ethanol subsidy = $0.00

Mixing Values

Benzene	Aromatics	Olefins	Oxygen	RVP
1.00%	25.70%	10.05%	1.68%	10.50

Major Components

Oxygenates	FCCN	Tol/Xy	Reformate	Butane	Alky	Imports	Naphthas
112.534	457.548	3,191	400,000	75,000	200,000	1,020,149	165,164
4.62%	18.80%	0.13%	16.44%	3.08%	8.22%	41.92%	6.79%

Average Cost ($/bbl) $31.24

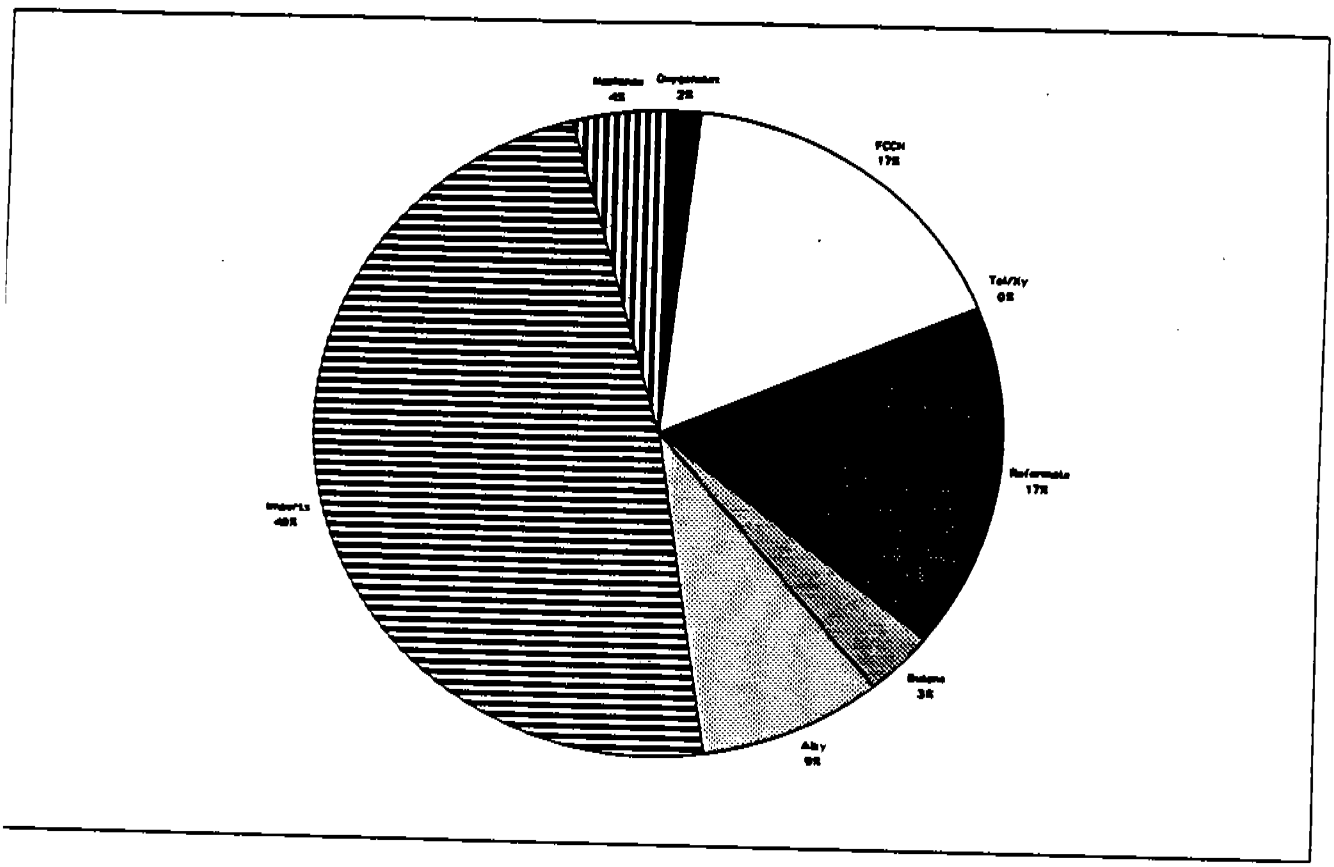
Average cost ($/gal) $0.74

Shadow Prices

	($/bbl)
3asoline	$32.697
FCCN	$0.000
Reformate	$0.000
Olefins	$0.000
Aromatics	($1.536)
Oxygen	$73.592
MON	$0.000
RON	$0.316
RVP: Max	($0.048)
Lt Olefins	$0.000
Benzene	($90.782)
ETOH Prod.	$1.613
MTBE	$13.699
TAME	$8.739
TAEE	$0.000
ETBE	$0.000
Alkylate	$0.000

ETOH	MTBE	TAME	TAEE	ETBE	N-butane	Toluene/ Xylene	Isomerate & Cnap		
$58.80	$39.30	$40.80	$51.86	$51.97	$18.52	$30.18	$25.30		
500	0	0	0	0	0	0	0	520,500	Lower Bound Total
42,401	40,000	10,000	0	30,000	75,000	7,800	6,500	3,289,864	Upper Bound Total
42,401	40,000	10,000	0	20,133	75,000	3,191	6,500	Mogas Volume 2,433,585	

PADD II Winter Gasoline: 1998 - Complex Option



APPENDIX E:

Shadow Price Tables for all REFORMGAS Model runs
(Base Case, Simple Option, Complex Option, California Standards, and Winter Opt-in)

Introduction

Although the primary focus of this study has dealt with the impacts of various scenarios and assumptions on the demand for ethanol and ethanol-based ethers, some concerns have been placed on the shadow prices, or the marginal costs of adding or extracting one barrel of a particular component from the gasoline pool. This concern has been addressed in the main text and specific REFORMGAS Model outputs pertaining to shadow prices have been presented. This appendix serves to consolidate all shadow price outputs from all model runs in a much less tedious manner than viewing the actual model output documentation (which is provided in previous sections of the Appendix).

This appendix presents several tables (Tables E.1 - E.4) which consolidate the shadow prices for all REFORMGAS Model runs conducted for this report. Additionally, Tables E.1 and E.2 include information on increases and/or decreases, on a percentage basis, of each scenario based on the existence of an ethanol subsidy as compared to its counterpart scenario excluding the ethanol subsidy. Specifically, Tables E.1 and E.2 present the shadow prices for the primary components; gasoline, olefins, aromatics, ethanol, ETBE, TAEE, TAME, and MTBE for the varying ethanol subsidy assumption -- with and without (w/o). The last "sub-Table" presents a direct comparison of the two complex option scenarios under the varying ethanol subsidy assumption. It is important to note that in Table E.2 (PADD III data) no Winter Opt-in data are available since no such model runs were executed. Again, this is a result of no severe CO non-attainment areas existing in the region and therefore, there is no reason for a winter fuels program to be initiated.

Tables E.3 and E.4 illustrate the shadow prices for the eight components in the presence of a free-market (no ethanol subsidy). These two tables are the counterparts to Tables 4.5 and 4.6 which demonstrate the shadow prices under subsidized market conditions.

Table E.1: Shadow Prices; PADD II

Shadow Prices of Gasoline, Ethers, and Oxygenates; PADD II (w/o Ethanol Subsidy)

COMPONENT	Summer Base	Summer Simple	Summer Complex	Summer CA	Winter Opt-in;	[- % Increase or Decrease From W/ to W/O Scenario -] Summer Base	Summer Simple	Summer Complex	Summer CA	Winter Opt-In;
Gasoline(w/o)	$59.79	$17.66	$59.01	$64.03	$32.70					
Gasoline	$35.54	$40.44	$41.34	$0.00	$33.00	-68.23%	228.99%	-42.74%	0.00%	100.92%
Olefine(w/o)	$0.00	$12.31	$0.00	$45.99	$0.00					
Olefine	$0.00	$7.60	$0.42	$7.90	$0.00	0.00%	-61.97%	0.00%	-482.15%	0.00%
Aromatics(w/o)	$0.00	$33.41	$11.92	$41.75	$1.54					
Aromatics	$5.33	$9.20	$0.00	$39.37	$1.54	0.00%	-263.15%	0.00%	-6.05%	100.00%
Ethanol(w/o)	($46.24)	($43.98)	$0.00	$0.00	$1.61					
Ethanol	$0.00	($1.18)	$0.00	$0.00	$32.44	0.00%	2.68%	0.00%	0.00%	2014.91%
ETBE(w/o)	$35.40	$32.77	$3.15	$26.73	$0.00					
ETBE	$0.00	$6.83	$2.12	$4.61	$13.72	0.00%	-379.80%	-48.58%	-479.83%	0.00%
TAEE(w/o)	$31.79	$29.94	$7.12	$14.19	$0.00					
TAEE	$0.00	$0.66	$0.00	$0.00	$6.68	0.00%	-4436.36%	0.00%	0.00%	0.00%
TAME(w/o)	$22.81	$20.55	$16.71	$31.45	$8.74					
TAME	$0.26	$7.45	$4.21	$4.98	$14.57	-8673.08%	-175.84%	-296.91%	-531.53%	168.70%
MTBE(w/o)	$20.84	$18.70	$11.14	$31.90	$13.70					
MTBE	$1.81	$9.36	$4.55	$6.82	$19.97	-1051.38%	-99.79%	-144.84%	-367.74%	145.77%

Shadow Prices of Gasoline, Ethers, and Oxygenates; PADD II

COMPONENT	(w/o Ethanol Subsidy) Summer Base	Summer Simple	Summer Complex	Summer CA	Winter Opt-in;	(w/Ethanol Subsidy) Summer Base	Summer Simple	Summer Complex	Summer CA	Winter Opt-in;
Gasoline	$59.79	$17.66	$59.01	$64.03	$32.70	$35.54	$40.44	$41.34	$0.00	$33.00
Olefine	$0.00	$12.31	$0.00	$45.99	$0.00	$0.00	$7.60	$0.42	$7.90	$0.00
Aromatics	$0.00	$33.41	$11.92	$41.75	$1.54	$5.33	$9.20	$0.00	$39.37	$1.54
Ethanol	($46.24)	($43.98)	$0.00	$0.00	$1.61	$0.00	($1.18)	$0.00	$0.00	$32.44
ETBE	$35.40	$32.77	$3.15	$26.73	$0.00	$0.00	$6.83	$2.12	$4.61	$13.72
TAEE	$31.79	$29.94	$7.12	$14.19	$0.00	$0.00	$0.66	$0.00	$0.00	$6.68
TAME	$22.81	$20.55	$16.71	$31.45	$8.74	$0.26	$7.45	$4.21	$4.98	$14.57
MTBE	$20.84	$18.70	$11.14	$31.90	$13.70	$1.81	$9.36	$4.55	$6.82	$19.97

Shadow Prices of Gasoline, Ethers, and Oxygenates; PADD II (for the Complex Option)

COMPONENT	Complex (w/o subs)	Complex (w/subs)
Gasoline	$59.01	$41.34
Olefine	$0.00	$0.42
Aromatics	$11.92	$0.00
Ethanol	$0.00	$0.00
ETBE	$3.15	$2.12
TAEE	$7.12	$0.00
TAME	$16.71	$4.21
MTBE	$11.14	$4.55

Table E.2: Shadow Prices; PADD III

Shadow Prices of Gasoline, Ethers, and Oxygenates; PADD III (w/o Ethanol Subsidy)

COMPONENT	Summer Base	Summer Simple	Summer Complex	Summer CA	Winter Opt-in;	[- % Increase or Decrease From W/ to W/O Scenario -] Summer Base	Summer Simple	Summer Complex	Summer CA	Winter Opt-in;
Gasoline(w/o)	$59.79	$53.48	$114.25	$62.73	N/A					
Gasoline		$45.01	$81.27	$267.83	N/A	0.00%	-18.82%	-40.58%	426.96%	
Olefins(w/o)	$0.00	$0.00	$0.00	$0.00	N/A					
Olefins		$0.00	$0.00	$27.78	N/A	0.00%	0.00%	0.00%	0.00%	
Aromatics(w/o)	$0.00	$25.37	$108.37	$40.19	N/A					
Aromatics		$12.87	$50.04	$301.31	N/A	0.00%	-97.13%	-116.57%	749.71%	
Ethanol(w/o)	$0.00	$0.00	($114.49)	($63.59)	N/A					
Ethanol		$0.00	($36.60)	($30.99)	N/A	0.00%	0.00%	31.97%	48.73%	
ETBE(w/o)	$4.35	$0.00	$33.71	$0.00	N/A					
ETBE		$0.32	$24.22	$145.26	N/A	0.00%	0.00%	-39.18%	0.00%	
TAEE(w/o)	$8.01	$2.19	$56.19	$0.00	N/A					
TAEE		$0.61	$34.45	$203.96	N/A	0.00%	-259.02%	-63.11%	0.00%	
TAME(w/o)	$17.70	$12.37	$59.62	$17.00	N/A					
TAME		$4.20	$34.73	$188.08	N/A	0.00%	-194.52%	-71.67%	1106.35%	
MTBE(w/o)	$12.74	$10.26	$18.26	$1.47	N/A					
MTBE		$2.95	$14.27	$73.90	N/A	0.00%	-247.80%	-27.96%	5027.21%	

Shadow Prices of Gasoline, Ethers, and Oxygenates; PADD III

COMPONENT	(w/o Ethanol Subsidy) Summer Base	Summer Simple	Summer Complex	Summer CA	Winter Opt-in;	(w/Ethanol Subsidy) Summer Base	Summer Simple	Summer Complex	Summer CA	Winter Opt-in;
Gasoline	$59.79	$53.48	$114.25	$62.73	N/A		$45.01	$81.27	$267.83	N/A
Olefins	$0.00	$0.00	$0.00	$0.00	N/A		$0.00	$0.00	$27.78	N/A
Aromatics	$0.00	$25.37	$108.37	$40.19	N/A		$12.87	$50.04	$301.31	N/A
Ethanol	$0.00	$0.00	($114.49)	($63.59)	N/A		$0.00	($36.60)	($30.99)	N/A
ETBE	$4.35	$0.00	$33.71	$0.00	N/A		$0.32	$24.22	$145.26	N/A
TAEE	$8.01	$2.19	$56.19	$0.00	N/A		$0.61	$34.45	$203.96	N/A
TAME	$17.70	$12.37	$59.62	$17.00	N/A		$4.20	$34.73	$188.08	N/A
MTBE	$12.74	$10.26	$18.26	$1.47	N/A		$2.95	$14.27	$73.90	N/A

Shadow Prices of Gasoline, Ethers, and Oxygenates; PADD III (for the Complex Option)

COMPONENT	Complex (w/o subs)	Complex (w/subs)
Gasoline	$114.25	$81.27
Olefins	$0.00	$0.00
Aromatics	$108.37	$50.04
Ethanol	($114.49)	($36.60)
ETBE	$33.71	$24.22
TAEE	$56.19	$34.45
TAME	$59.62	$34.73
MTBE	$18.26	$14.27

Table E.3: Shadow Prices of Gasoline, Ethers, and Oxygenates; PADD II (Without Ethanol Subsidy)					
Component	**Shadow Price ($/bbl)**				
	Summer Base Case	**Summer Simple Option**	**Summer Complex Option**	**Summer CA Standards**	**Winter Opt-in; Complex Option**
Gasoline	$59.79	$17.66	$59.01	$64.03	$32.70
Olefins	$0.00	$12.31	$0.00	$45.99	$0.00
Aromatics	$0.00	$33.41	$11.92	$41.75	$1.54
ETOH	($46.24)	($43.98)	$0.00	$0.00	$1.61
ETBE	$35.40	$32.77	$3.15	$26.73	$0.00
TAEE	$31.79	$29.94	$7.12	$14.19	$0.00
TAME	$22.81	$20.55	$16.71	$31.45	$8.74
MTBE	$20.84	$18.70	$11.14	$31.90	$13.70

Table E.4: Shadow Prices of Gasoline, Ethers, and Oxygenates; PADD III (Without Ethanol Subsidy)					
Component	**Shadow Price ($/bbl)**				
	Summer Base Case	**Summer Simple Option**	**Summer Complex Option**	**Summer CA Standards**	**Winter Opt-in; Complex Option**
Gasoline	$59.79	$53.48	$114.25	$62.73	N/A
Olefins	$0.00	$0.00	$0.00	$0.00	N/A
Aromatics	$0.00	$25.37	$108.37	$40.19	N/A
ETOH	$0.00	$0.00	($114.49)	($63.59)	N/A
ETBE	$4.35	$0.00	$33.71	$0.00	N/A
TAEE	$8.01	$2.19	$56.19	$0.00	N/A
TAME	$17.70	$12.37	$59.62	$17.00	N/A
MTBE	$12.74	$10.26	$18.26	$1.47	N/A

N/A Winter (Complex Option) Opt-in Scenario not relative to PADD III region since no CO non-attainment areas exist in the region.